ECOSTRESS Urban Heat Vulnerability

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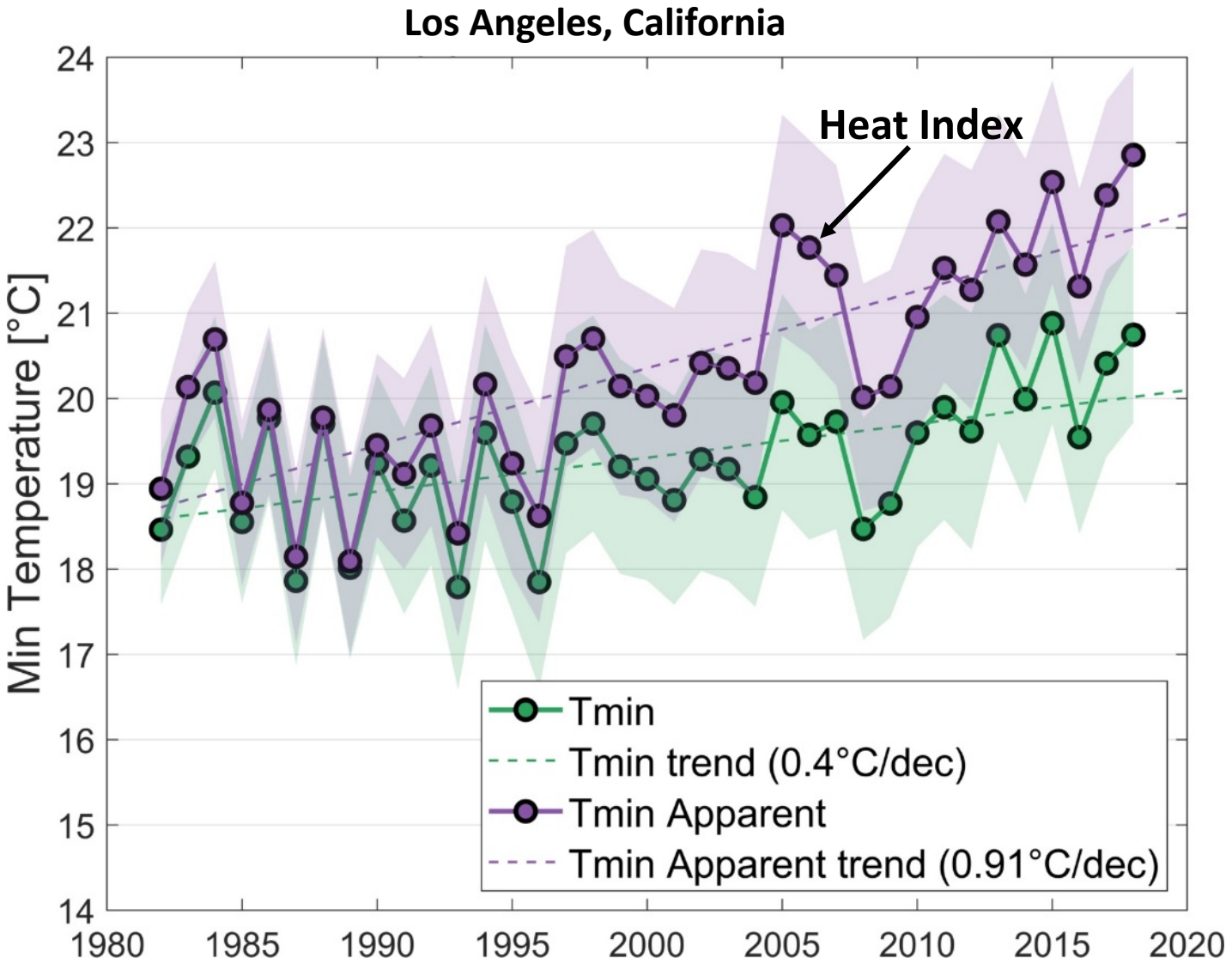
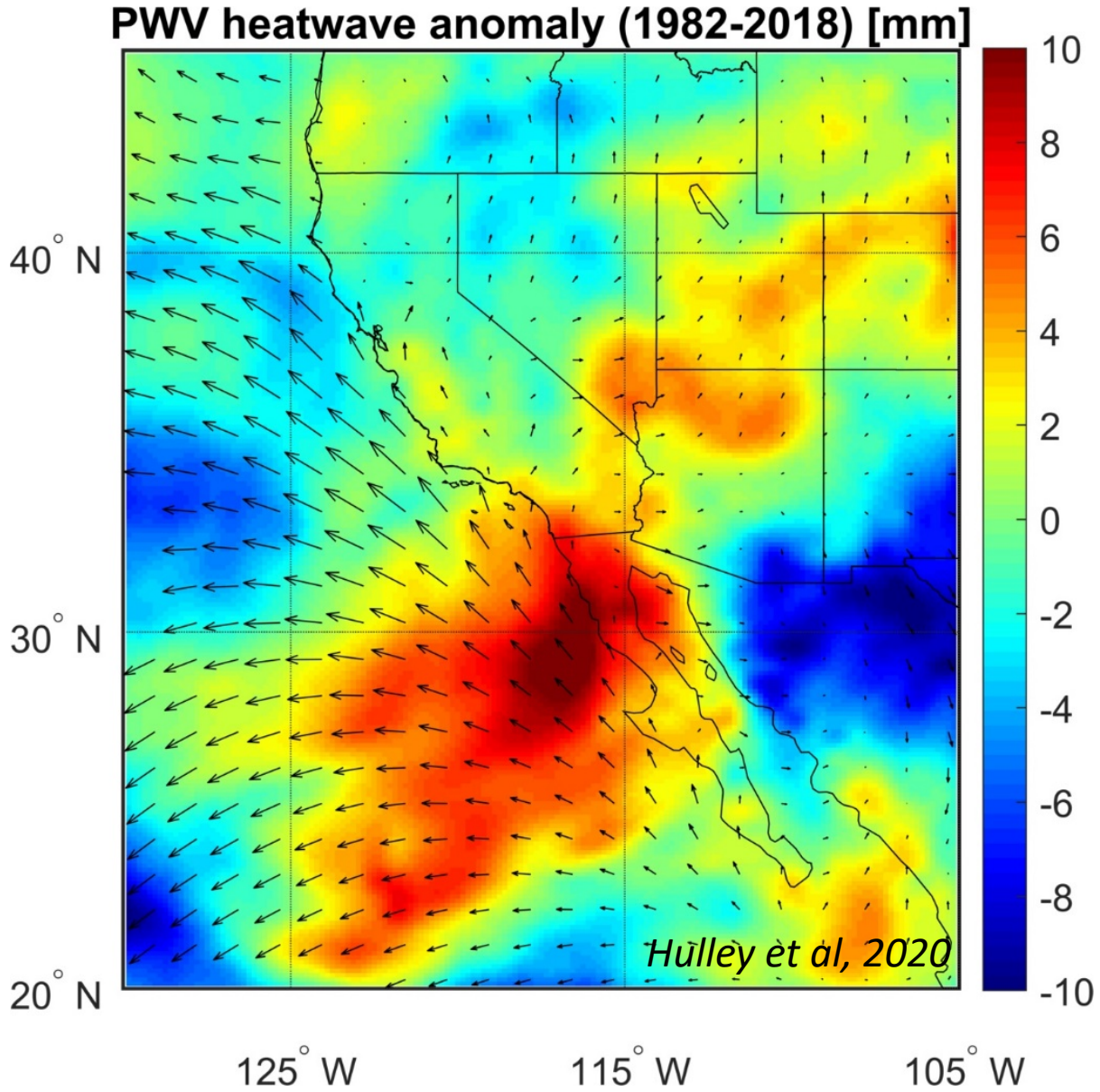
21st century nighttime heatwaves in Southern California are becoming hotter and more humid

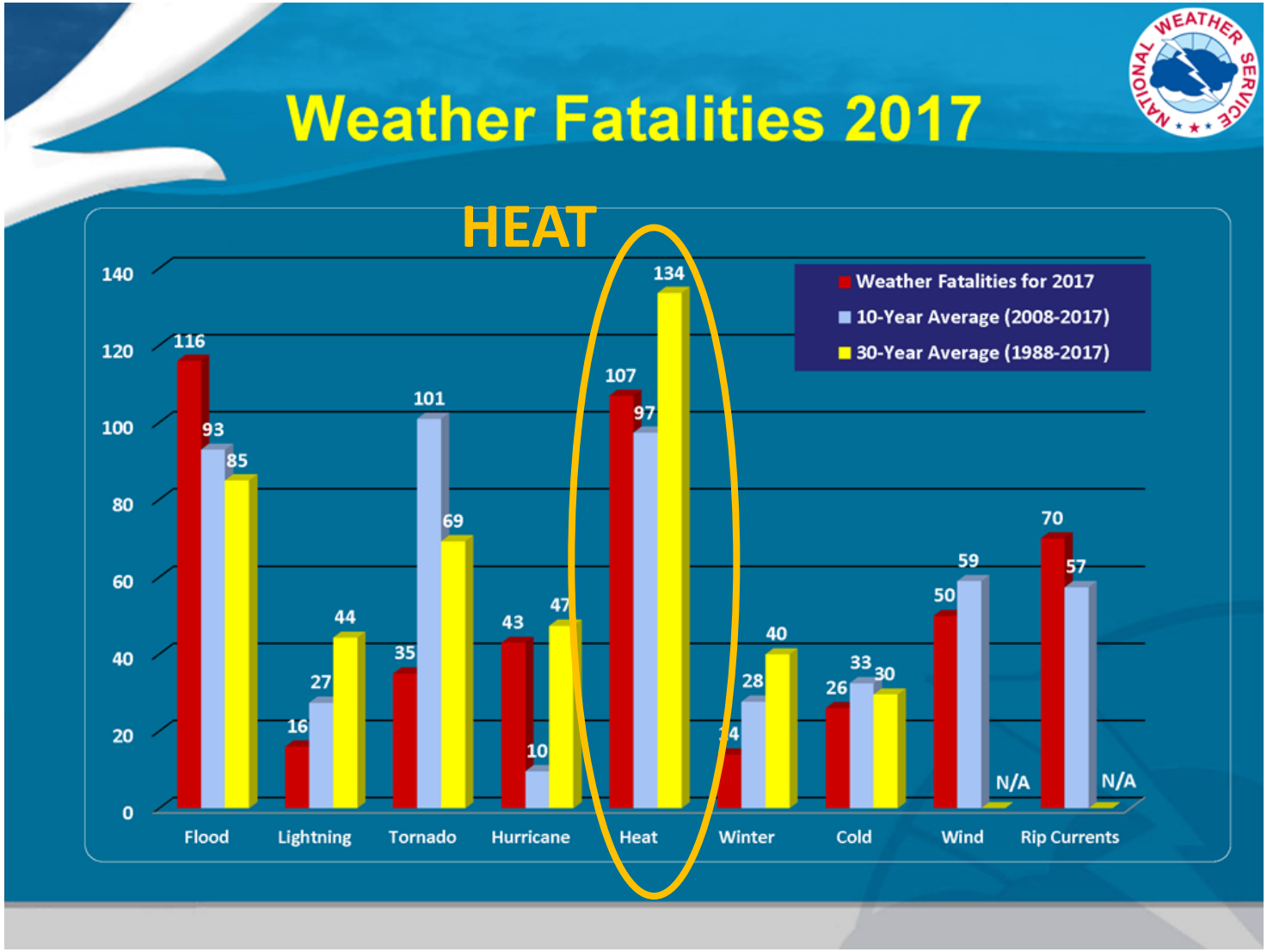


[*Hulley et al, Earth's Future, 2020*]

21st century nighttime heatwaves in Southern California are becoming hotter and more humid



……Humid, nighttime heatwaves are closely linked to human mortality and morbidity (Anderson and Bell, 2011; Hajat et al. 2002)



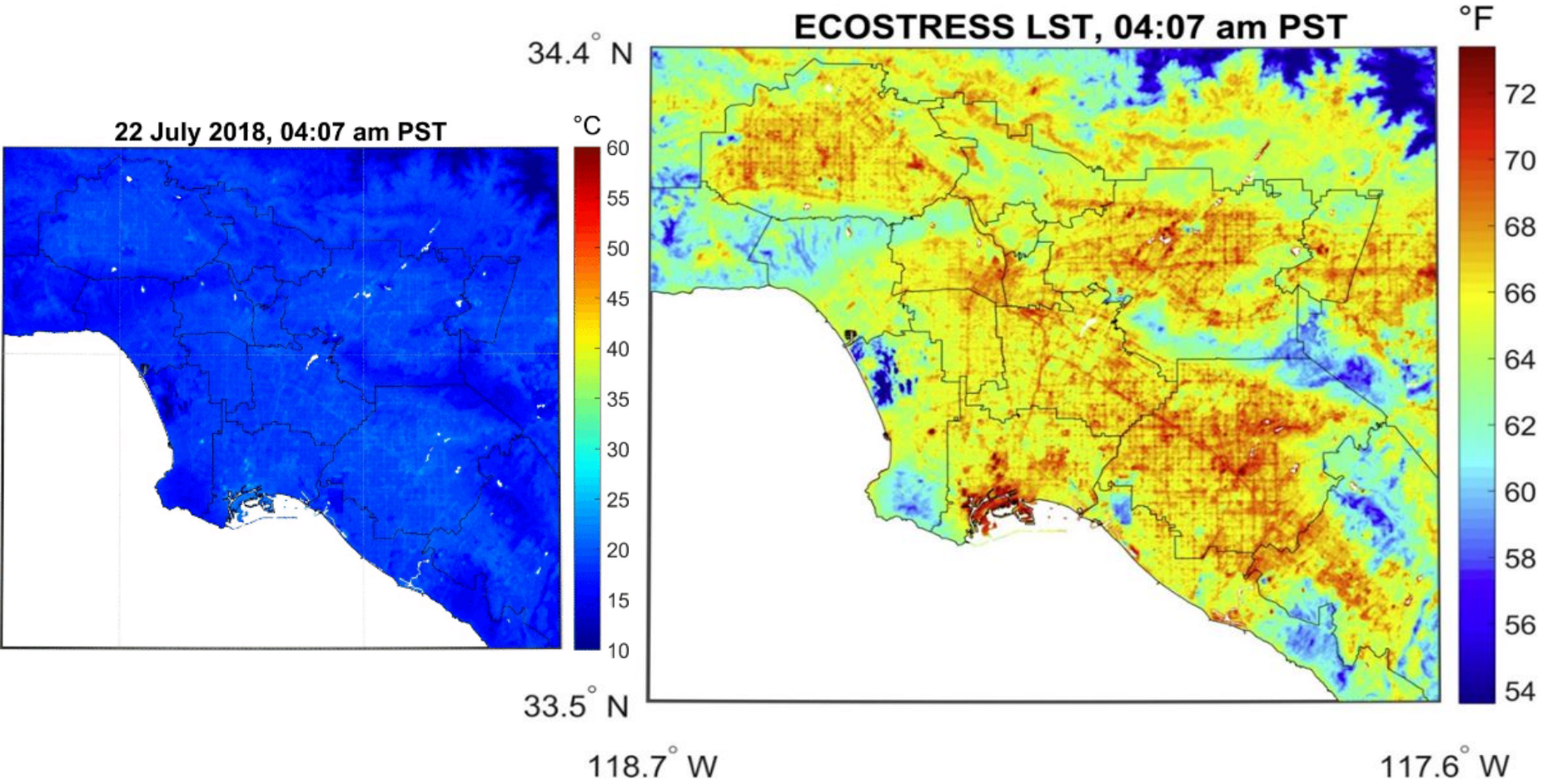
Source: http://www.nws.noaa.gov/om/hazstats.shtml

TIR Remote Sensing of Urban Heat

	MODIS Aqua (2002)	ECOSTRESS (2018)	HyTES (2013)	Fluke camera
				
Platform	Aqua spacecraft	International Space Station	Twin Otter	Hand-held
Spatial resolution	1000 m	70 m	1- 10 m	0.93 mRad
Temporal resolution	Daily 1:30 am/pm	3-5 days Diurnal cycle	Dedicated campaigns	Continuous
Altitude	705 km	400 km	1- 5 km	Ground

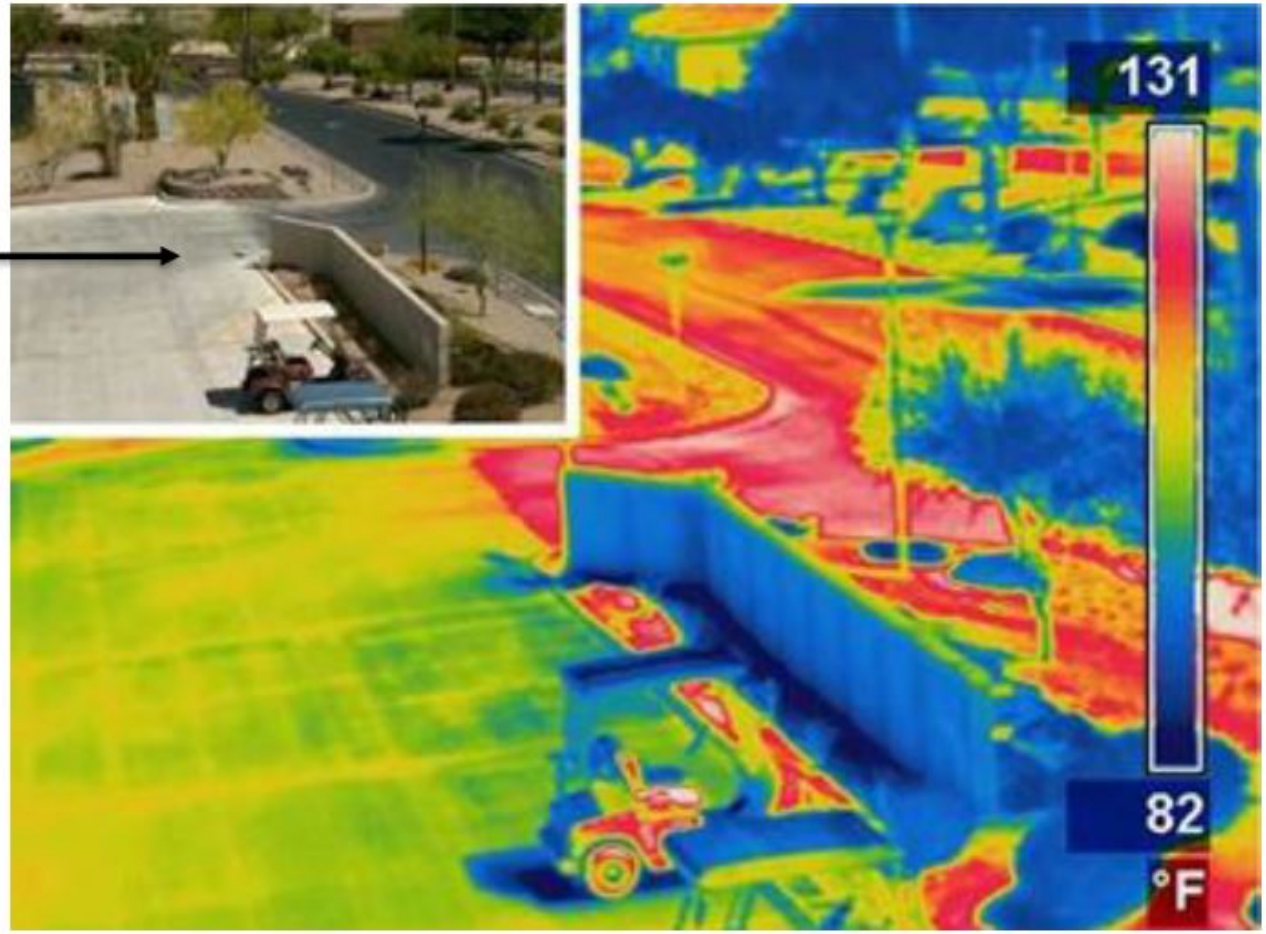
NEWS | SEPTEMBER 18, 2018

ECOSTRESS Maps LA's Hot Spots



Black asphalt absorbs more heat than concrete and other lighter colored pavements

Grey parking lot surface temperature is lower than black roadway



In July 2015, BSS partnered with Rec & Parks and GSD to Install a Test Patch of Cool Pavement Coating at Balboa Sports Complex

Two Coats of Guard Top Cool Seal are applied

Finished Product with striping

CITY OF LOS ANGELES
STREETS LA

June 2019: Installed Two More Neighborhood-Level Cool Pavement Projects

Sun Valley, Cool Seal on 13 Residential Blocks

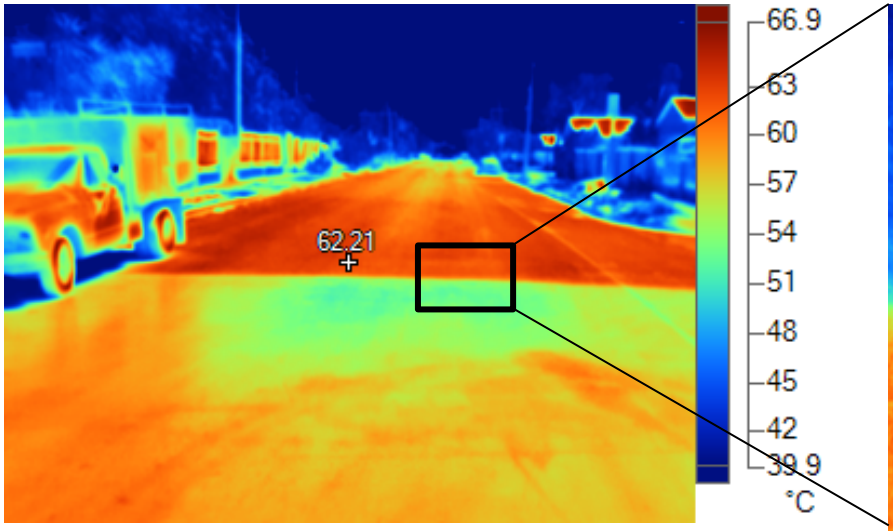
July 2019 Test Results:
Difference between surface temp of cool pavement and nearby black asphalt, when ambient temp is at least 90 deg F

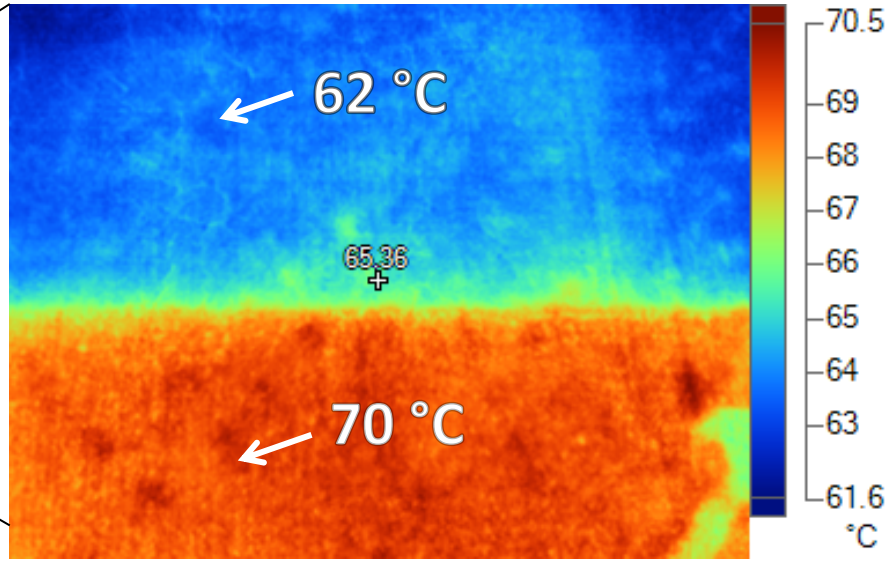
1) Sun Valley Neighborhood: -12.4 deg F
2) Beachy St: -12.1
3) Coronado St: -11.4
4) Pacoima Neighborhood: -10.1
5) Avenue 33: -10.0
6) Winnnetka Neighborhood: -9.4

All locations are Guard Top Cool Seal except Ave 33 which is a Cool Slurry prototype by PMI

‘Cool’ road with CoolSeal paint is up to **12 °C (17%)** cooler than regular asphalt. September 2019

JPL Fluke thermal camera





Heat Vulnerability Index (HVI) Model

$$HVI = E_i(x) + S_i(y) - R_i(z)$$

$E_i(x)$ ***Exposure***

x = Land Surface Temperature (LST) → **ECOSTRESS**

$S_i(y)$ ***Sensitivity***

y = Socio-Demographic Data (poverty, elderly etc)

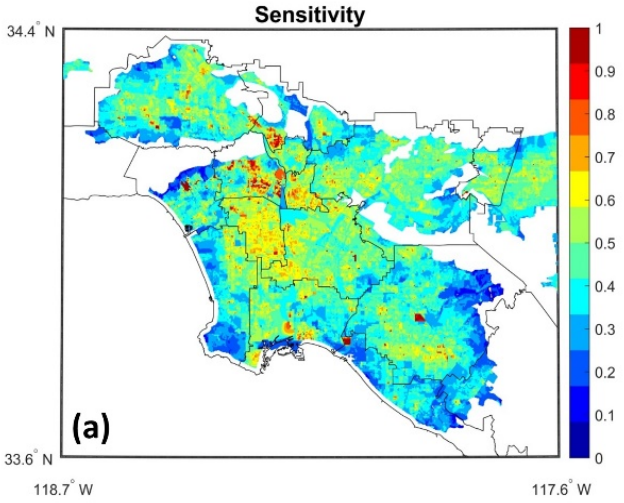
(source: SEDAC, 200m)

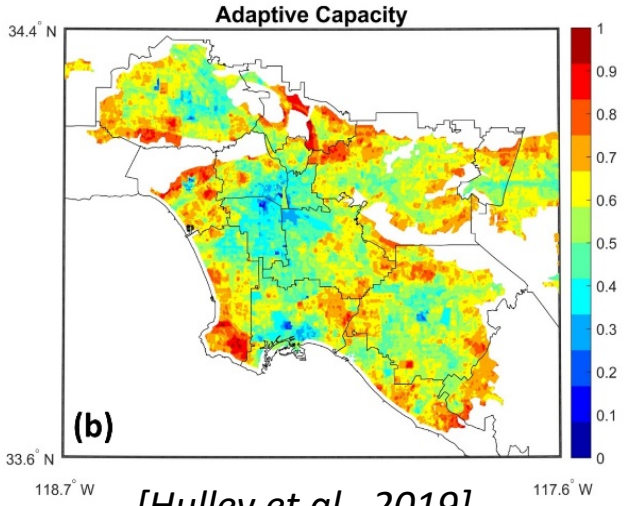
$R_i(z)$ ***Resilience***

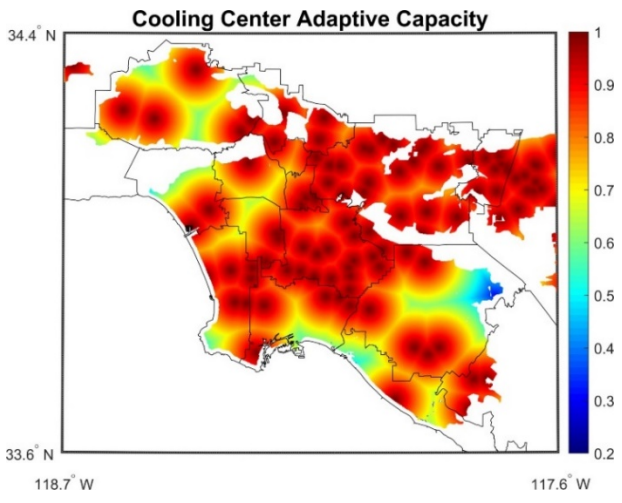
z = Vegetation fraction, Annual Income, Education

Principal Component (PC) Analysis

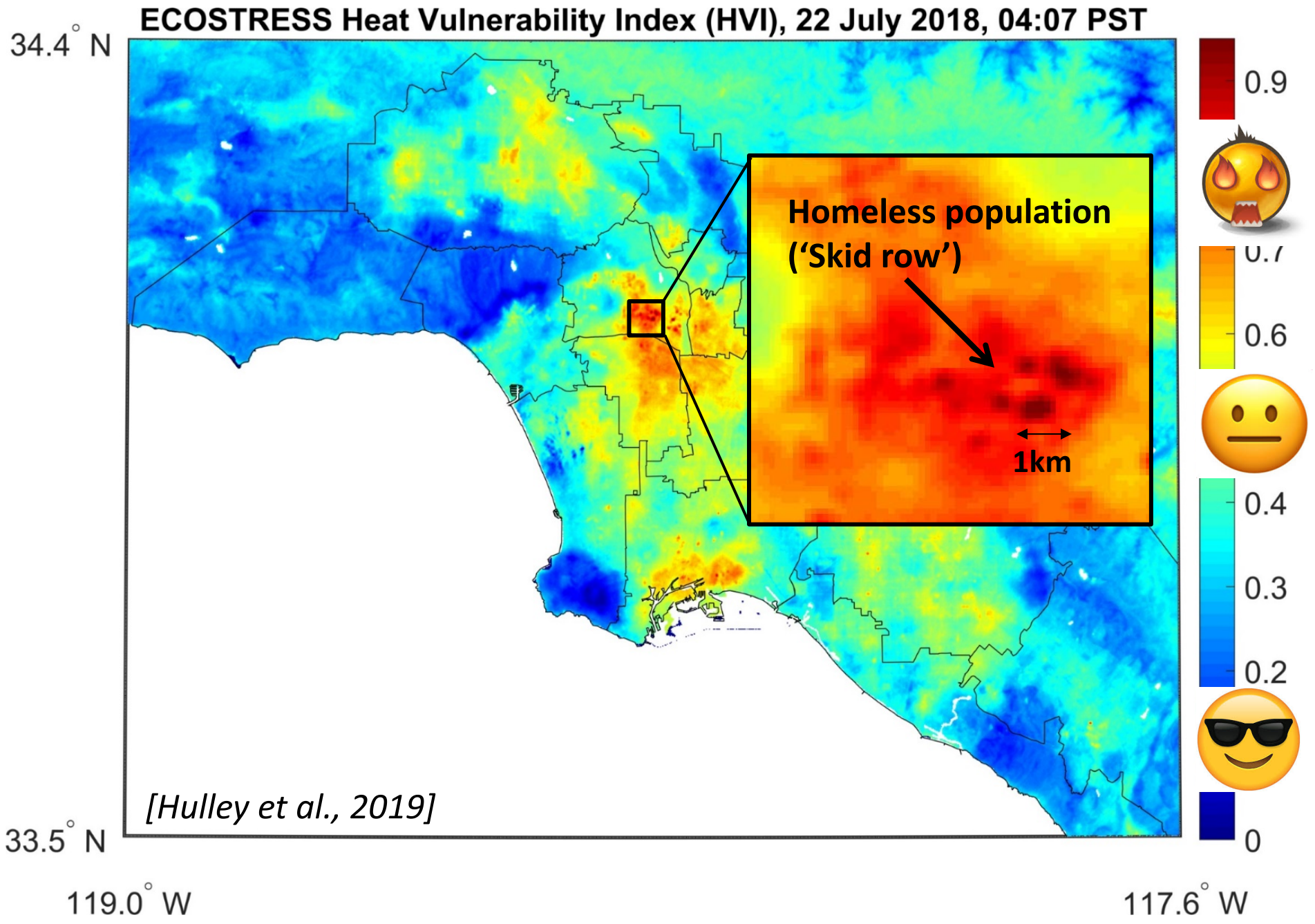
		PC1	PC2	PC3	PC4
Adaptability 1 "Socioeconomic status"	Green vegetation fraction	0.42	−0.05	0.13	−0.02
	Income	0.50	−0.06	−0.05	−0.01
	Education	0.47	0.09	−0.11	−0.07
Sensitivity 1 "Congestion"	Elderly	0.11	0.62	0.03	−0.15
	Population density	−0.11	0.57	−0.08	−0.03
	Building height	−0.12	0.42	−0.04	0.24
Sensitivity 2 "Isolation"	Poverty	−0.36	0.12	0.21	−0.04
	Disabled	0.01	−0.08	0.67	−0.07
	Unemployment	−0.23	−0.07	0.48	−0.05
Adaptability 2	Cooling center proximity	−0.11	−0.11	−0.16	0.82



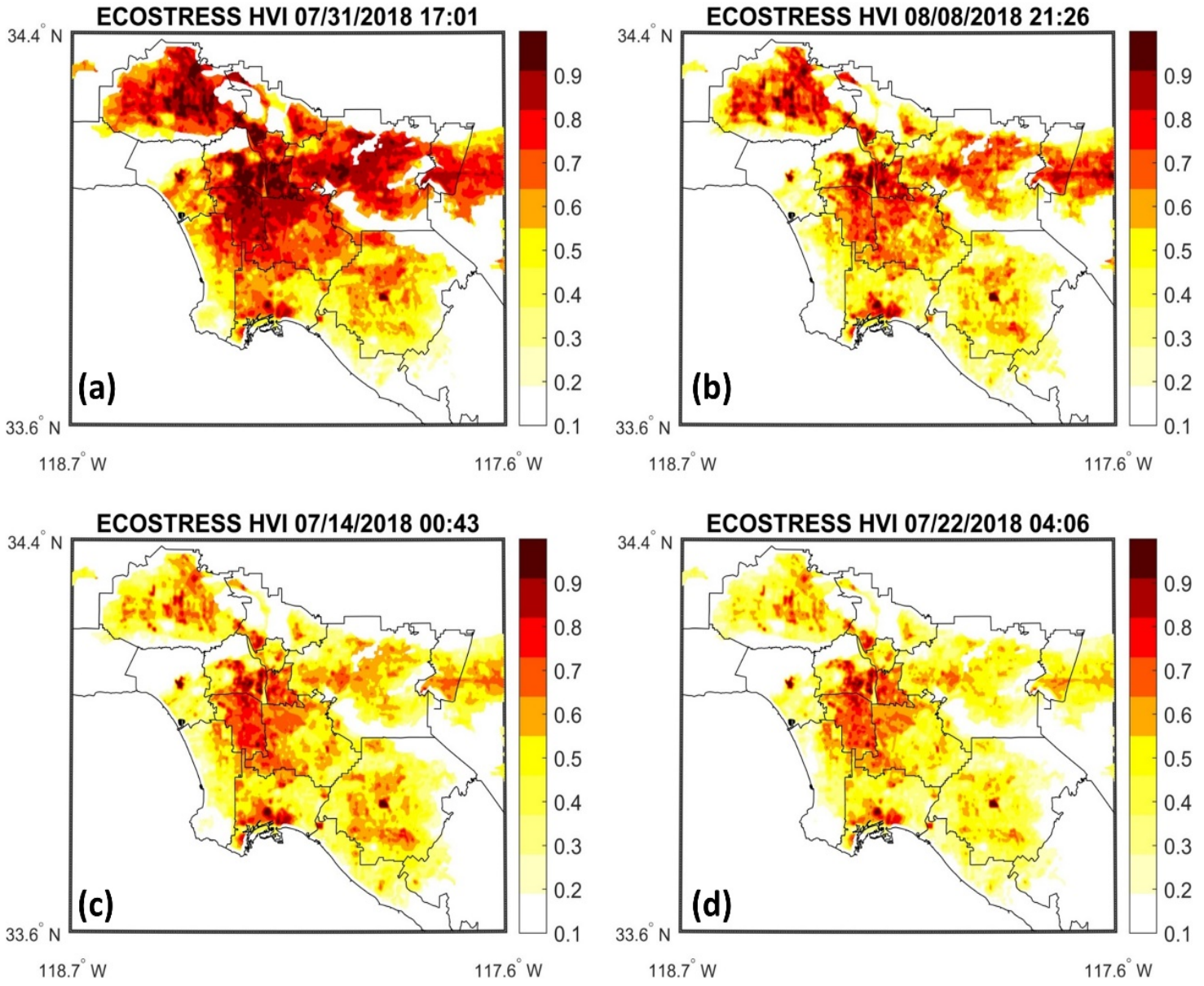




[Hulley et al., 2019]

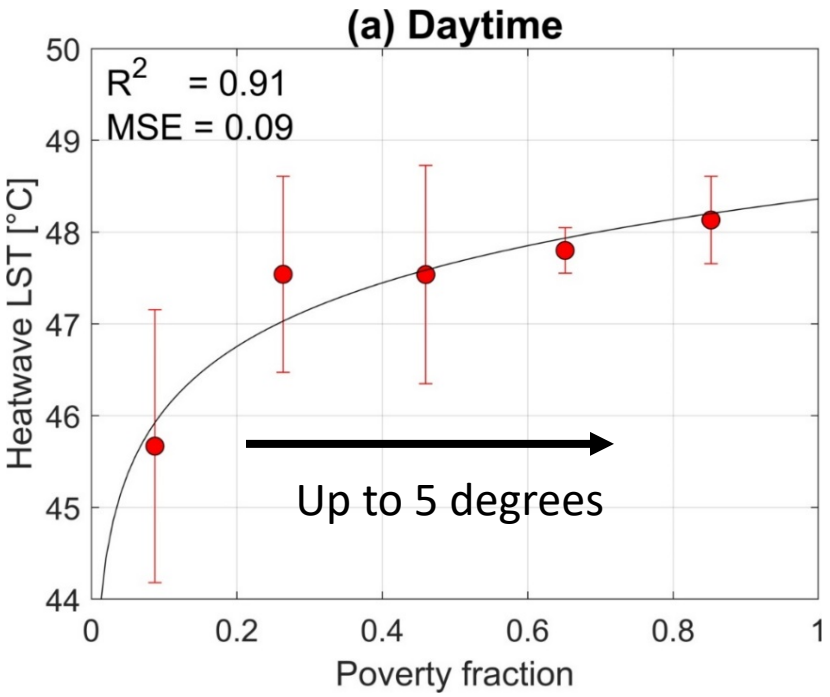

ECOSTRESS Heat Vulnerability Index (HVI), 22 July 2018, 04:07 PST
34.4° N
33.5° N
119.0° W
117.6° W
Homeless population
('Skid row')
1km
0.9
0.6
0.4
0.3
0.2
0
[Hulley et al., 2019]

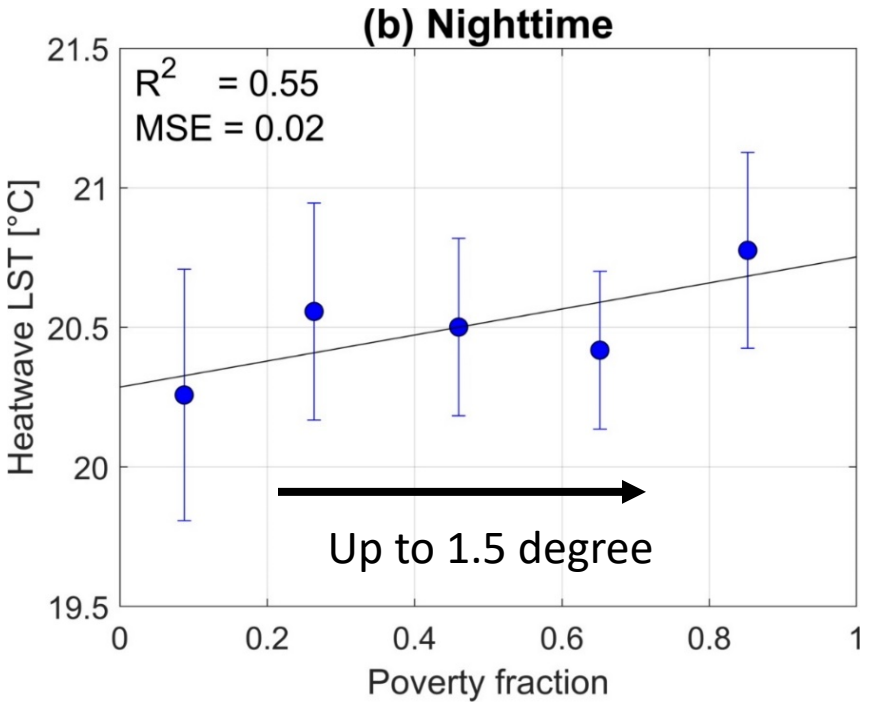
ECOSTRESS HVI persistence over the diurnal cycle



[Hulley et al., 2019]

Poorer neighborhoods suffer more from extreme heat than others…





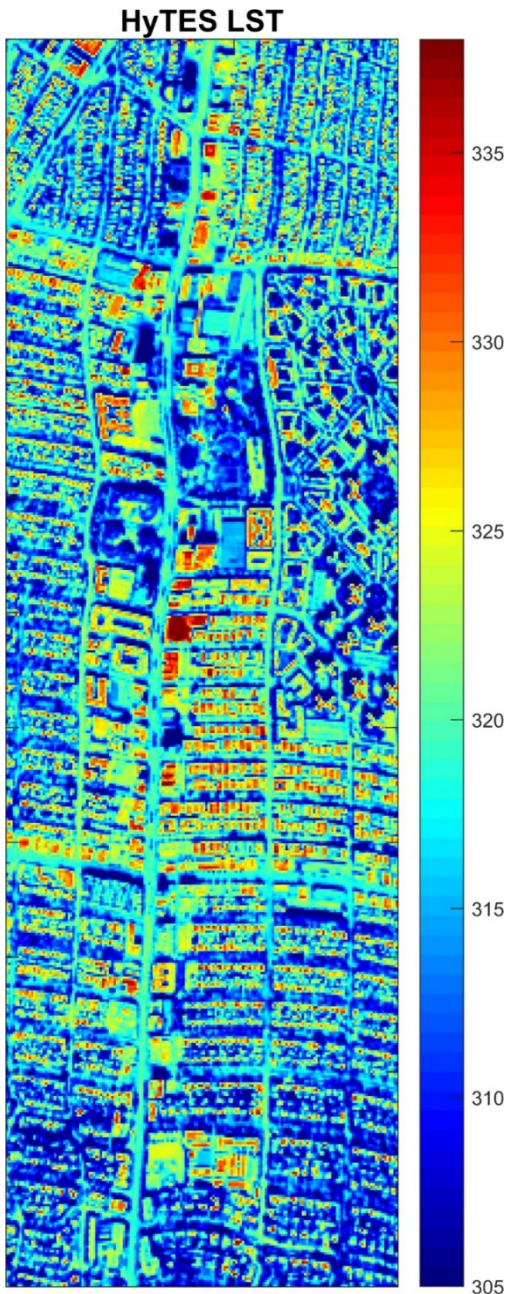
ECOSTRESS Heat Vulnerability Ranking by County Region

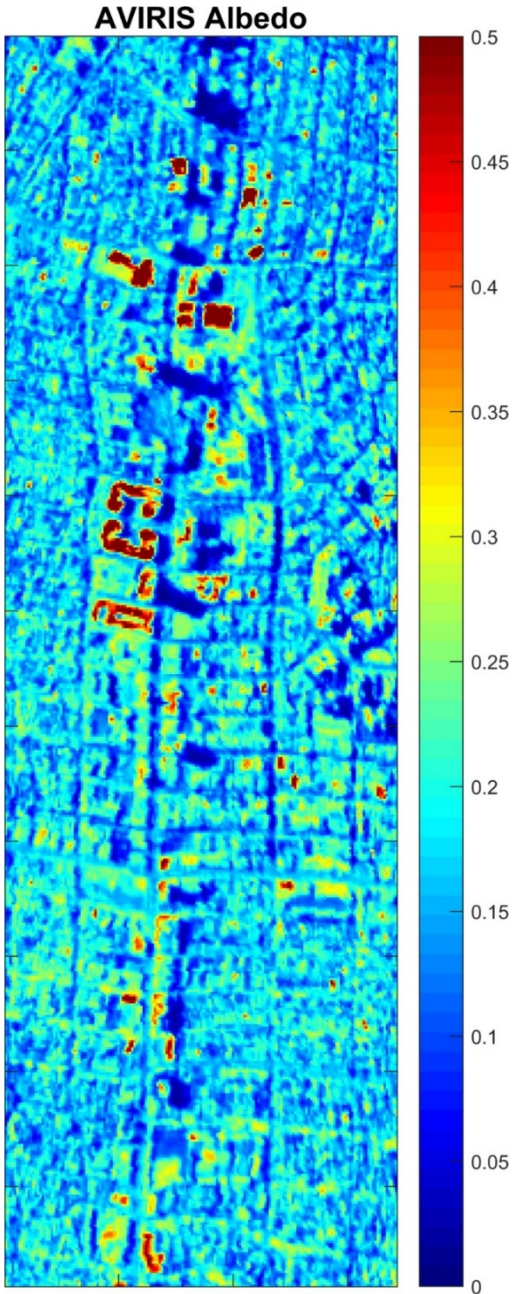
Vulnerability Ranking	HVI (%) (mean ± SD)	Number of Cooling Centers	Green Space (%)	Temperature (°C) (mean ± SD)
1. East LA	76 ± 8	0	14	29.0 ± 0.8
2. South LA	72 ± 10	3	15	27.8 ± 1.0
3. Central LA	64 ± 19	1	18	27.4 ± 1.5
4. Southeast LA	61 ± 10	13	18	27.5 ± 1.2
5. Pomona Valley	59 ± 14	9	24	28.8 ± 1.7
6. Northeast LA	58 ± 10	3	25	28.6 ± 1.1
7. San Fernando	58 ± 15	5	26	29.6 ± 1.5
8. San Gabriel	56 ± 12	13	26	29.4 ± 2.0
9. Harbor	53 ± 14	11	18	25.2 ± 1.5
10. Verdugos	50 ± 19	4	32	29.0 ± 1.4
11. North County	47 ± 12	1	25	25.5 ± 2.1
12. South Bay	37 ± 18	3	23	23.9 ± 1.5
13. Westside	36 ± 17	2	30	24.6 ± 1.3
14. Beach cities	30 ± 12	0	25	17.6 ± 3.5
15. Santa Monica	30 ± 6	0	39	25.1 ± 1.6
16. South County	27 ± 9	0	27	20.5 ± 2.9

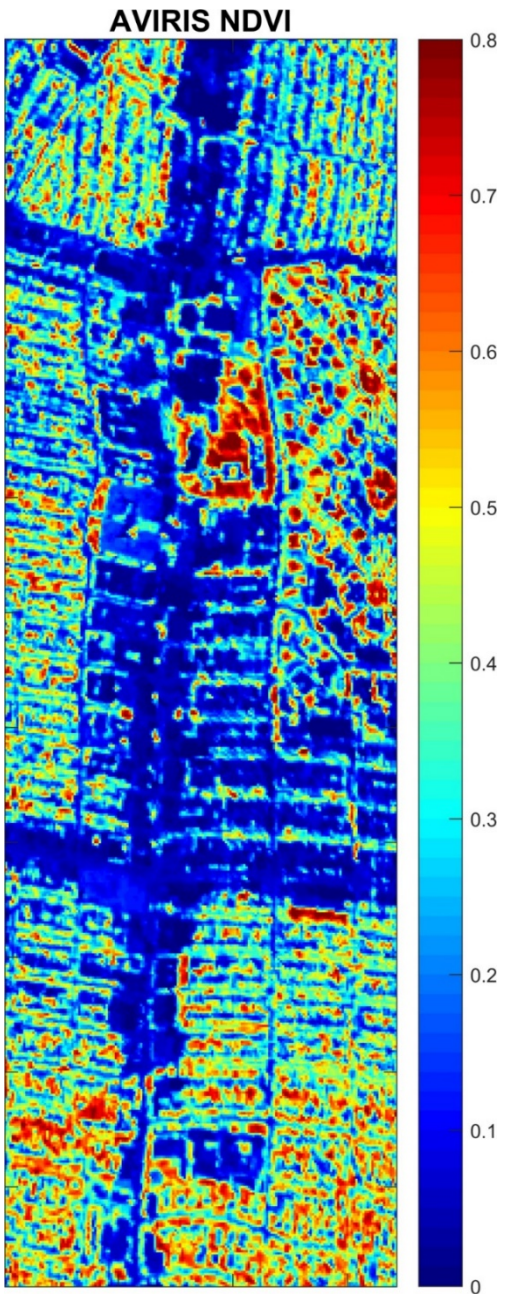
Thermal Infrared Remote Sensing

	MODIS (2000)	ECOSTRESS (2018)	HyTES (2013)	Fluke camera
				
Platform	Terra spacecraft	International Space Station	Twin Otter	Hand-held
Spatial resolution	1000 m	70 m	1- 10 m	0.93 mRad
Temporal resolution	Daily	3-5 days	Dedicated campaigns	n/a
Altitude	705 km	400 km	1- 5 km	Ground

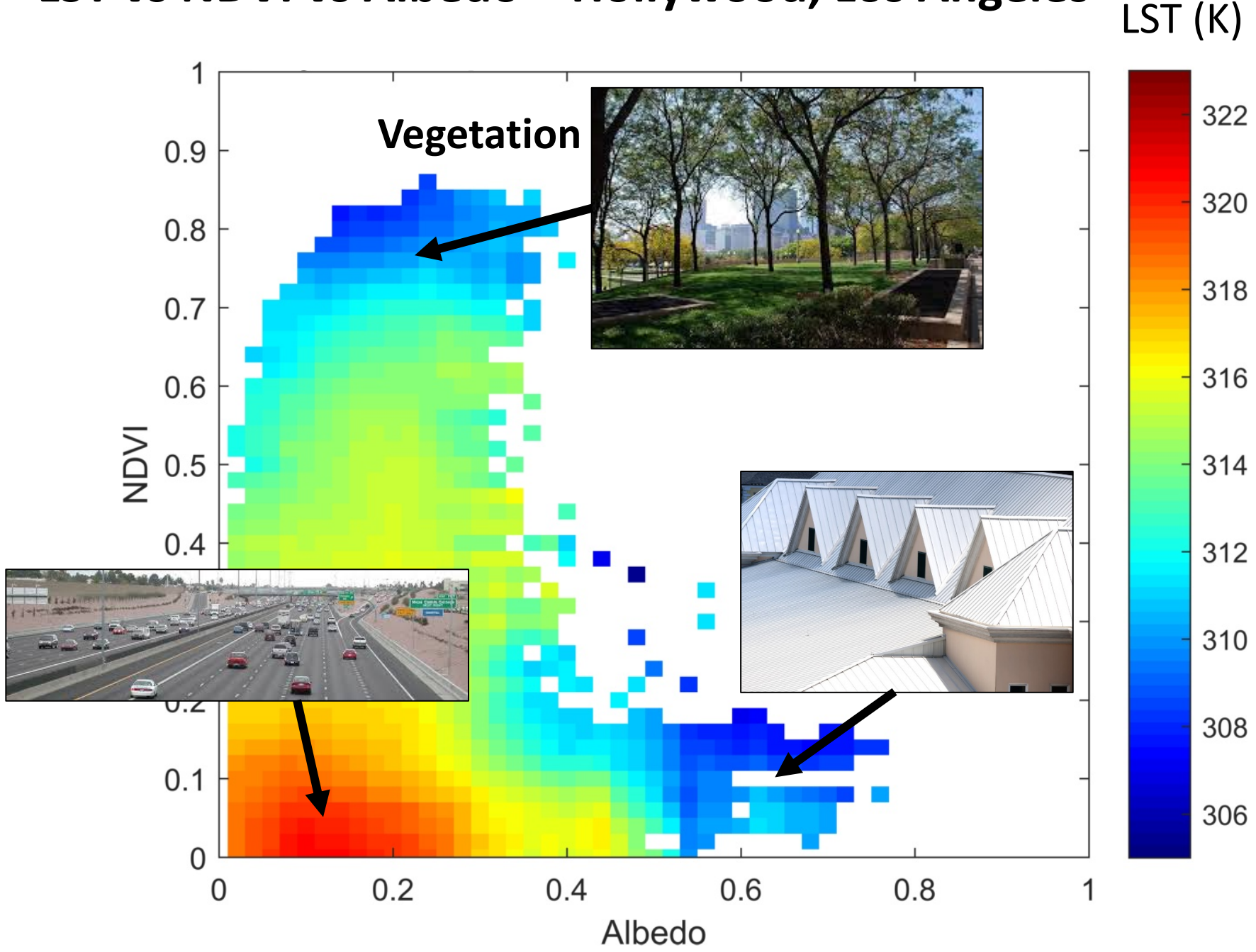
High resolution (2-3m) airborne hyperspectral data – La Brea, LA







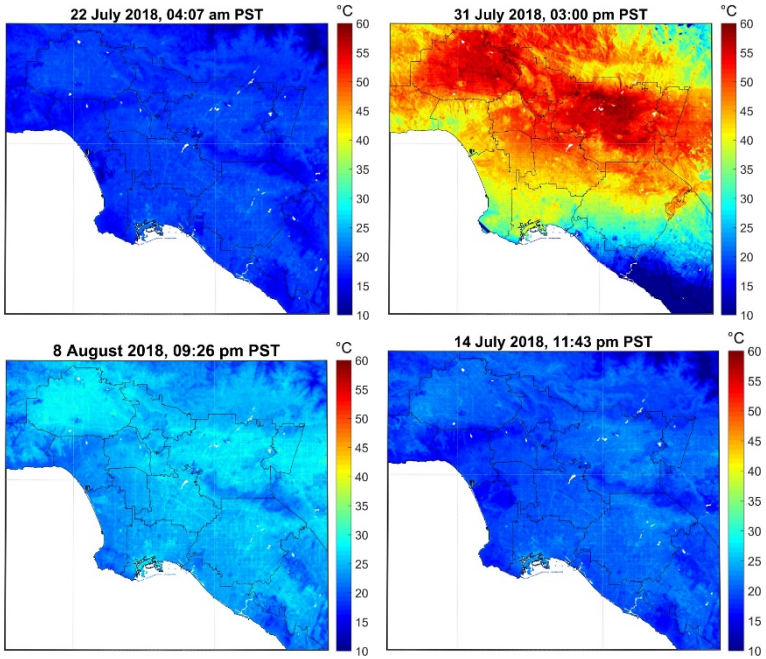
LST vs NDVI vs Albedo – Hollywood, Los Angeles



High resolution Urban Thermal Sharpener (HUTS) Multivariate Regression Model (Dominguez et al. 2011)

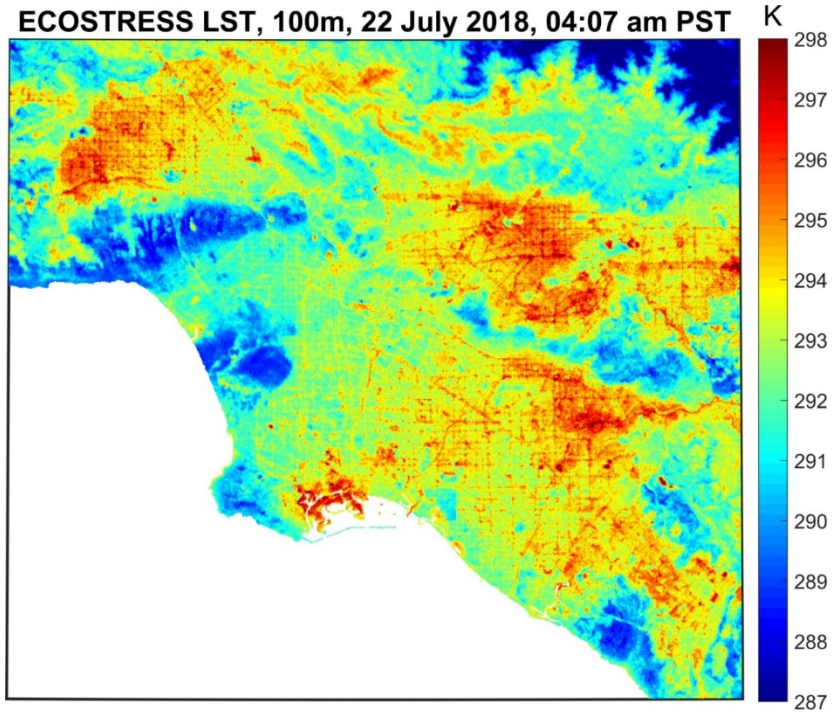
$$LST_{sharp} = p_1 NDVI^4 + p_2 NDVI^3 \cdot \alpha + p_3 NDVI^2 \cdot \alpha^2 + p_4 NDVI \cdot \alpha^3 + p_5 \alpha^4 + p_6 NDVI^3 + p_7 NDVI^2 \cdot \alpha + p_8 NDVI \cdot \alpha^2 + p_9 \alpha^3 + p_{10} NDVI^2 + p_{11} NDVI \cdot \alpha + p_{12} \alpha^2 + p_{13} NDVI + p_{14} \alpha + p_{15} + \mathrm{dLST}$$

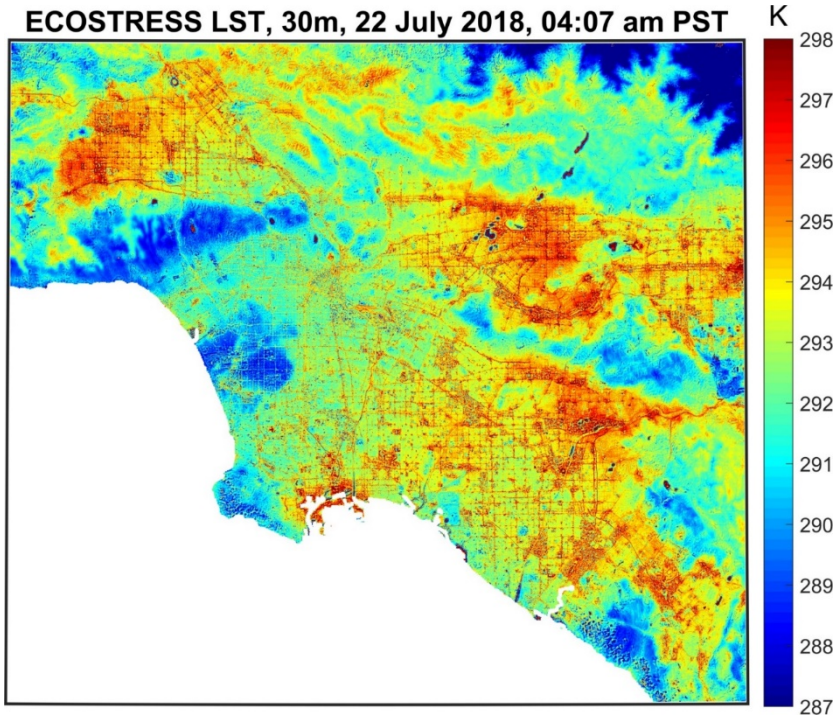
dLST = Energy balance conservation

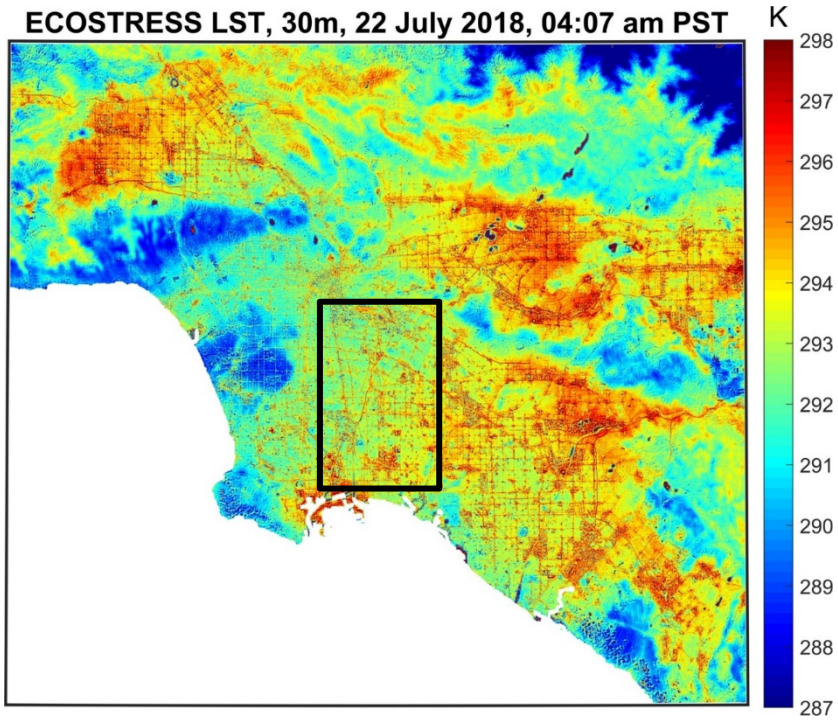


ECOSTRESS		Landsat/Sentinel
LST (09:30)	=	f1(NDVI, α)
LST (12:30)	=	f2(NDVI, α)
LST (14:30)	=	f3(NDVI, α)
	....	
	....	
LST (21:00)	=	f4(NDVI, α)
LST (04:00)	=	f5(NDVI, α)

Application to ECOSTRESS data to produce 30m urban LST






ECOSTRESS LST, 30m, 22 July 2018, 04:07 am PST
K
298
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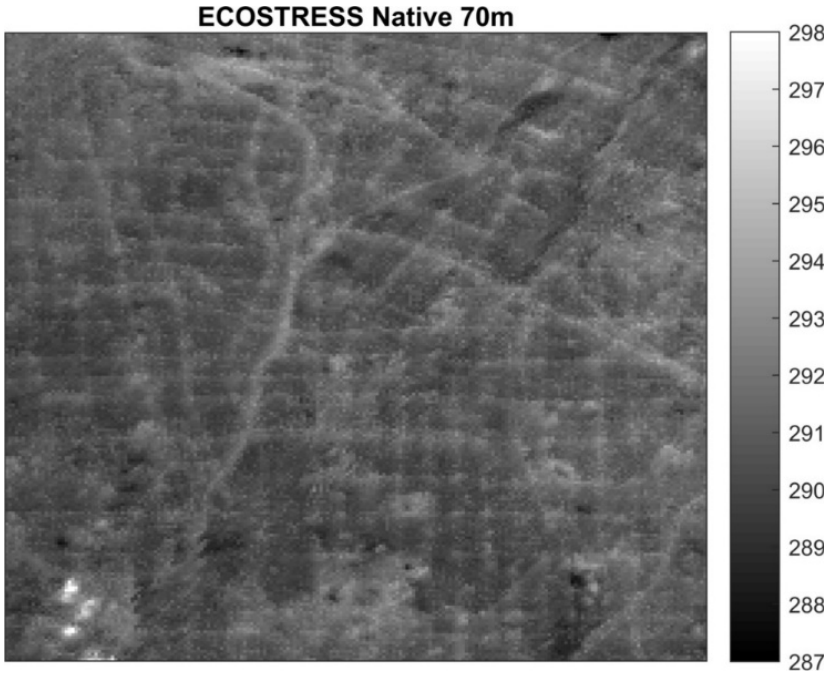
288
287


ECOSTRESS Native 70m
298
297
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288
287


ECOSTRESS Sharpened 30m
298
297
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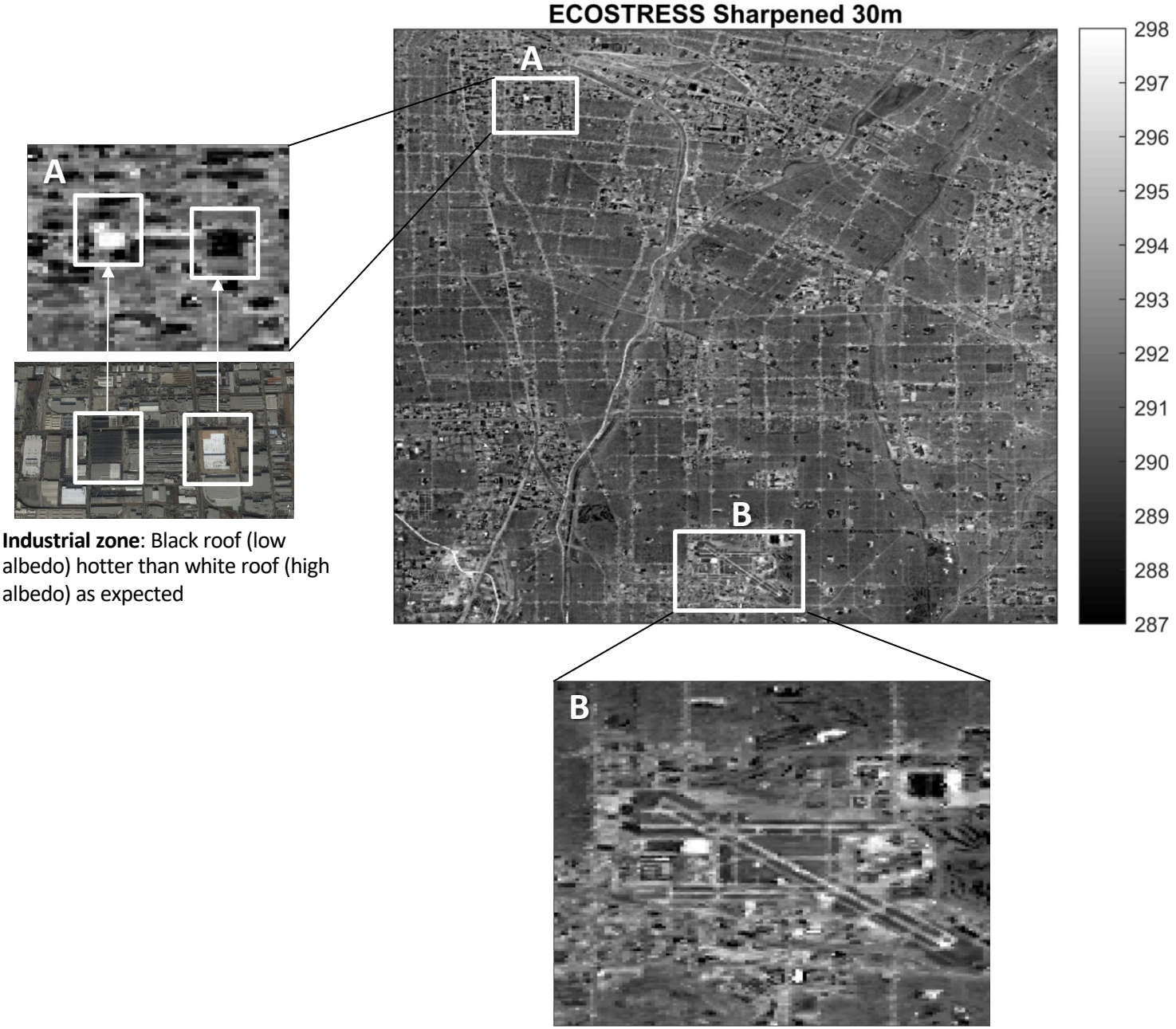
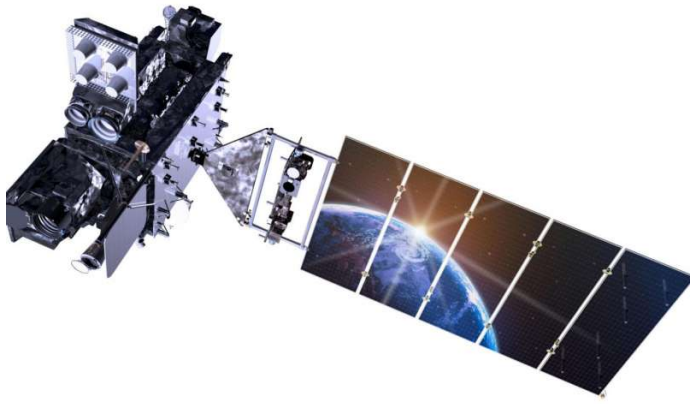


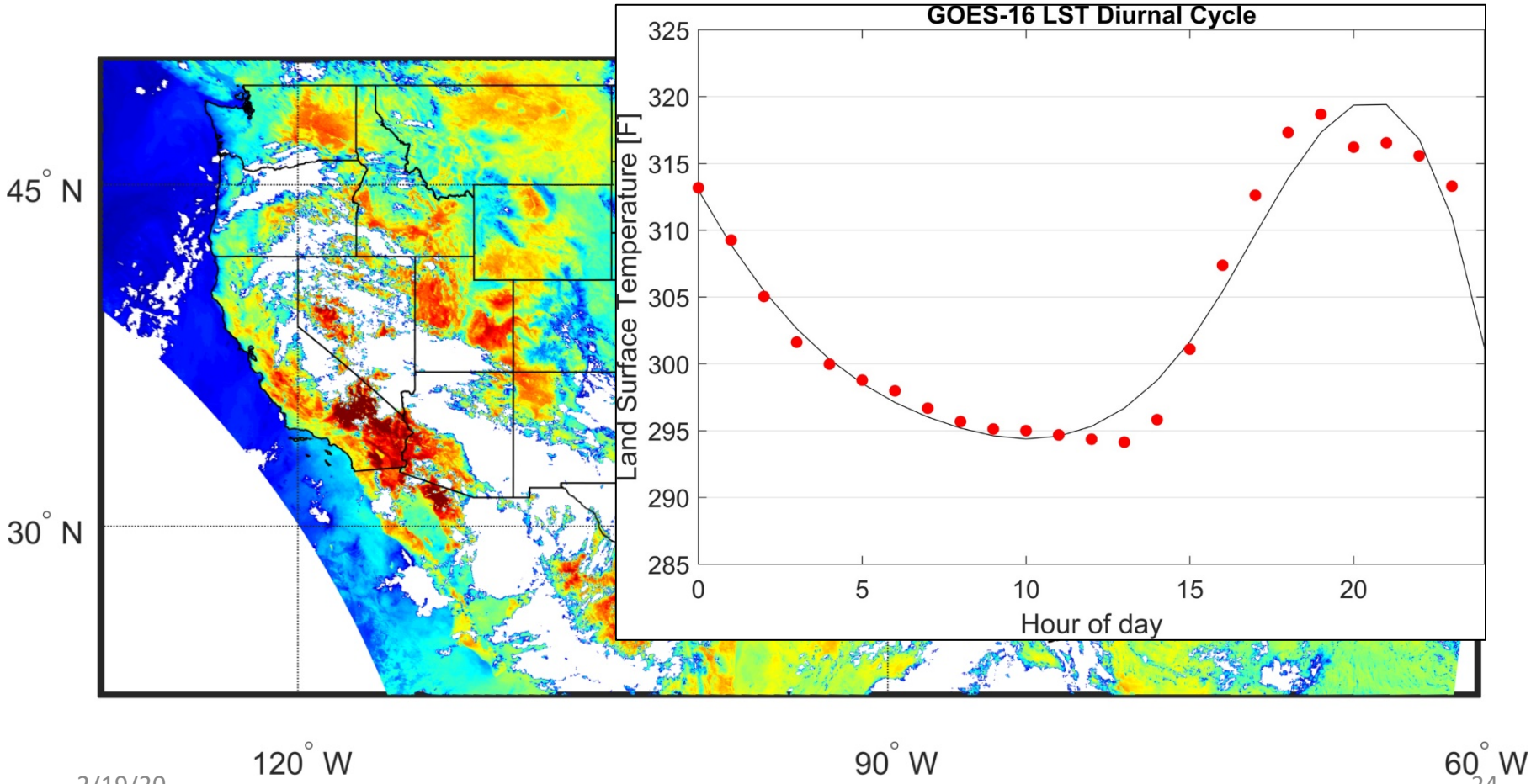
Industrial zone: Black roof (low albedo) hotter than white roof (high albedo) as expected

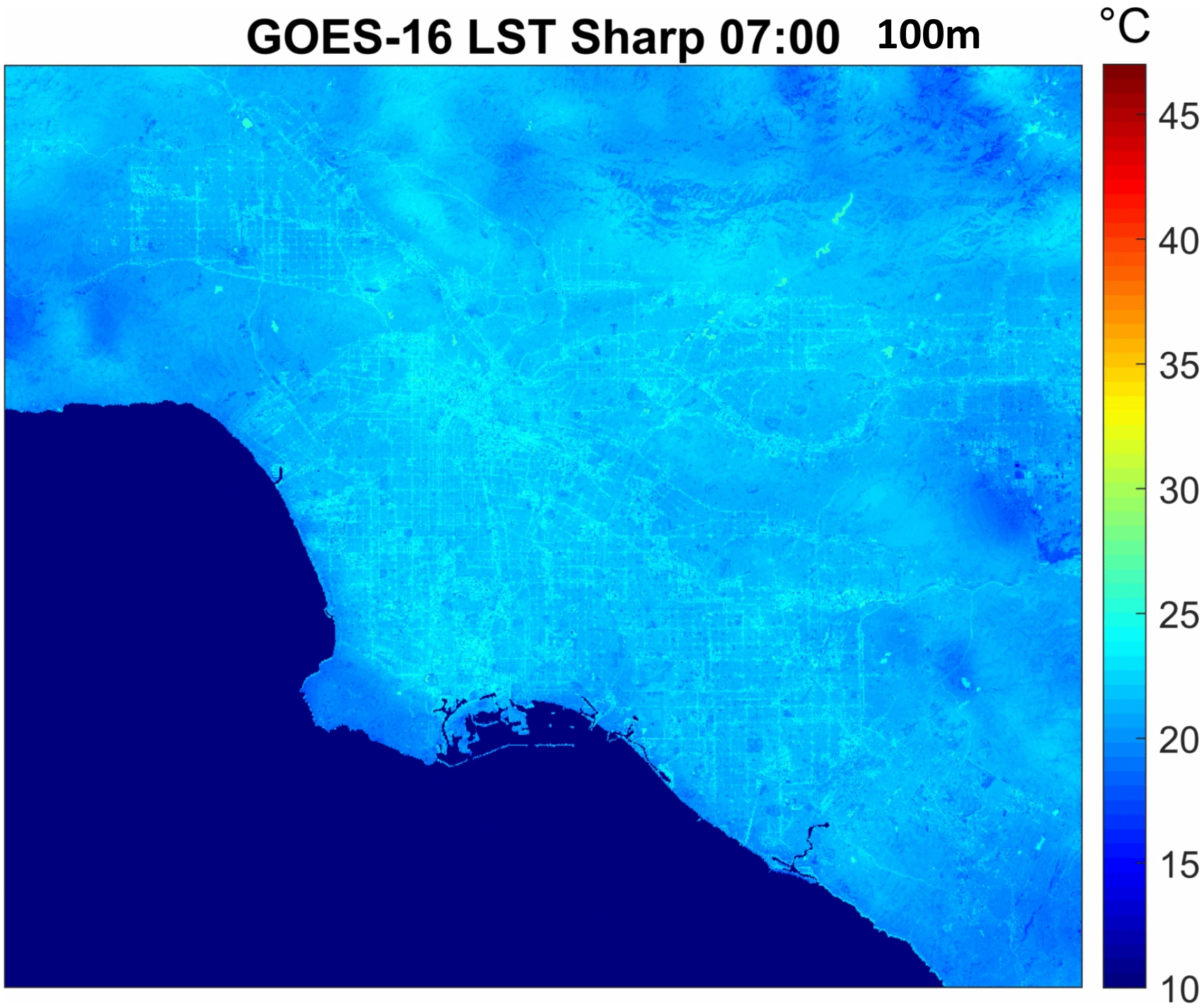
Long beach airport: runways and buildings hot, grass between runways cooler

GOES 16 (East) and 17 (West)



- 3 thermal bands 8-12 micron
- Spatial: **2.5-3 km**
- Temporal: **5 minutes**

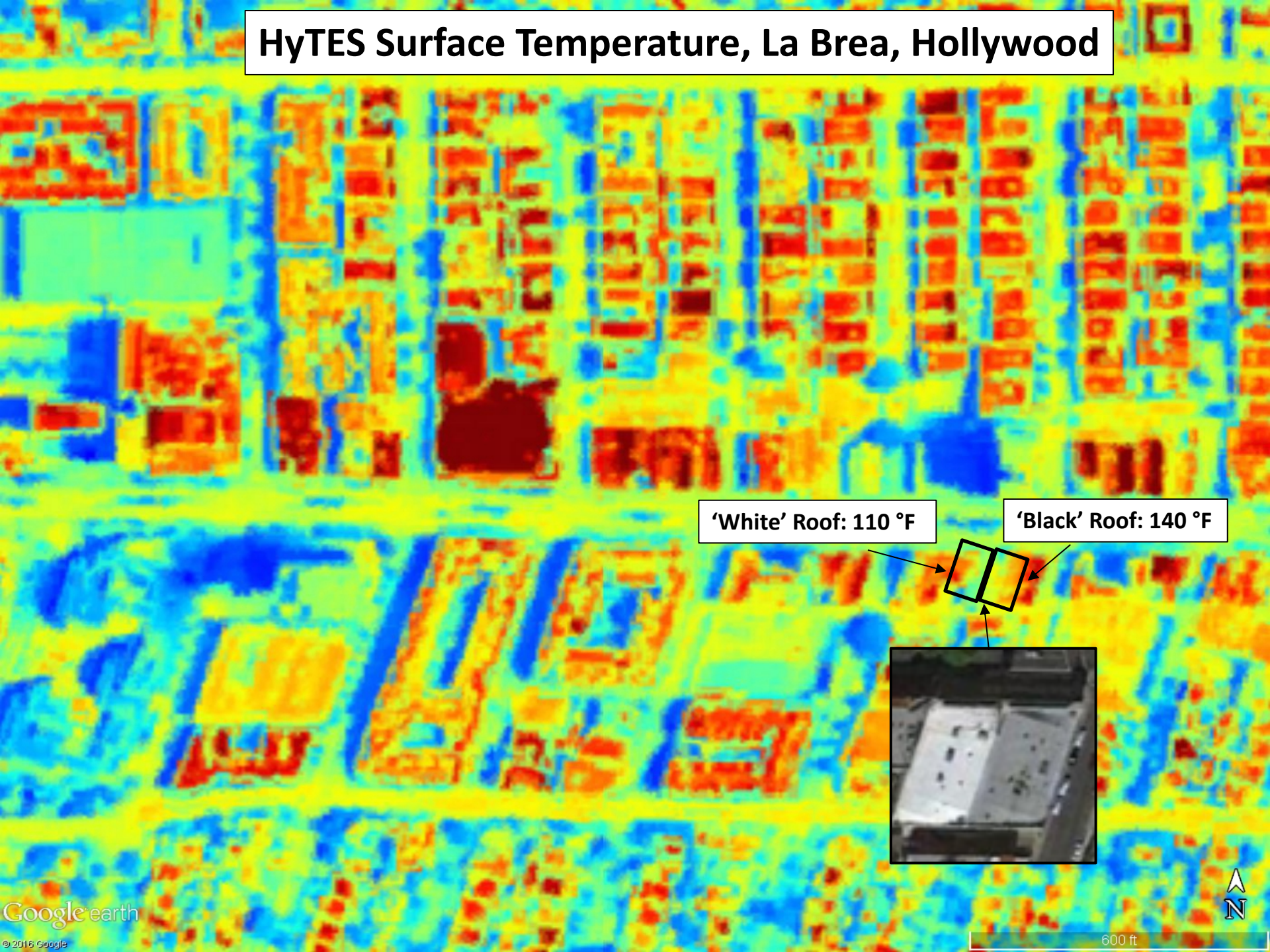



GOES-16 LST Sharp 07:00
100m
°C
45
40
35
30
25
20
15
10

Questions?

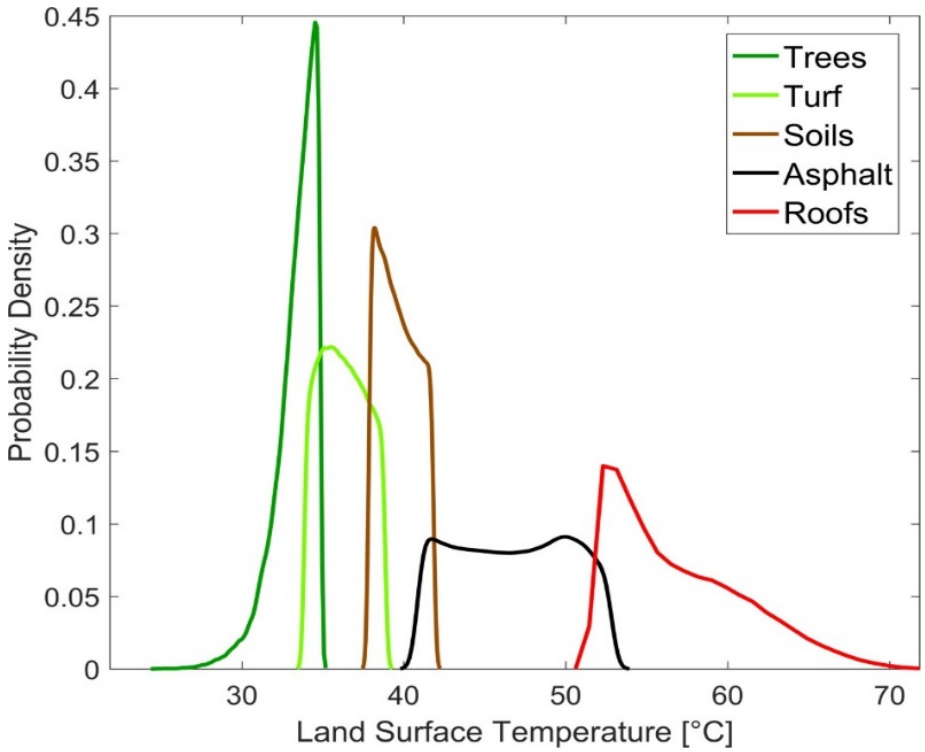
glynn.hulley@jpl.nasa.gov

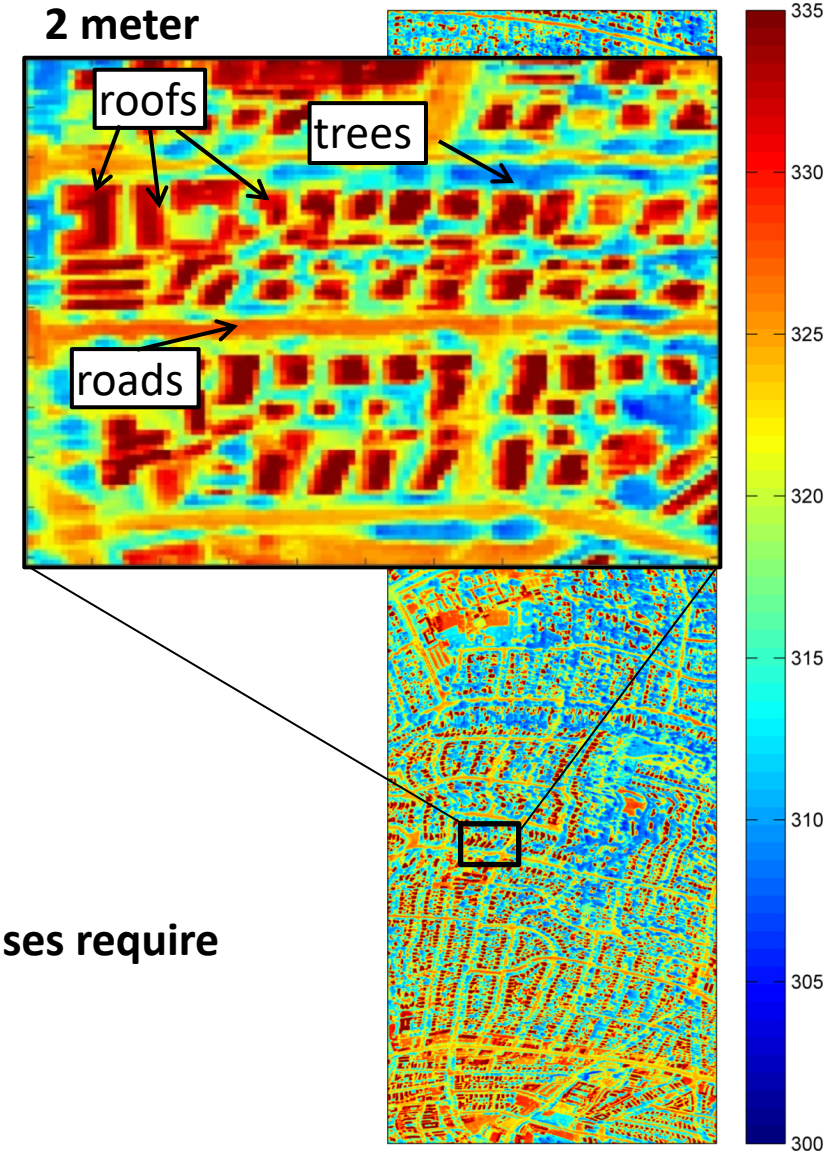
HyTES Surface Temperature, La Brea, Hollywood



Urban Heat Island Mapping

Hulley et al., RSE, 2019





- **LA city council mandate since 2015 is all new houses require cool roof technology implementation**

Thermal Infrared Remote Sensing

	MODIS (2000)	ECOSTRESS (2018)	HyTES (2013)	Fluke camera
				
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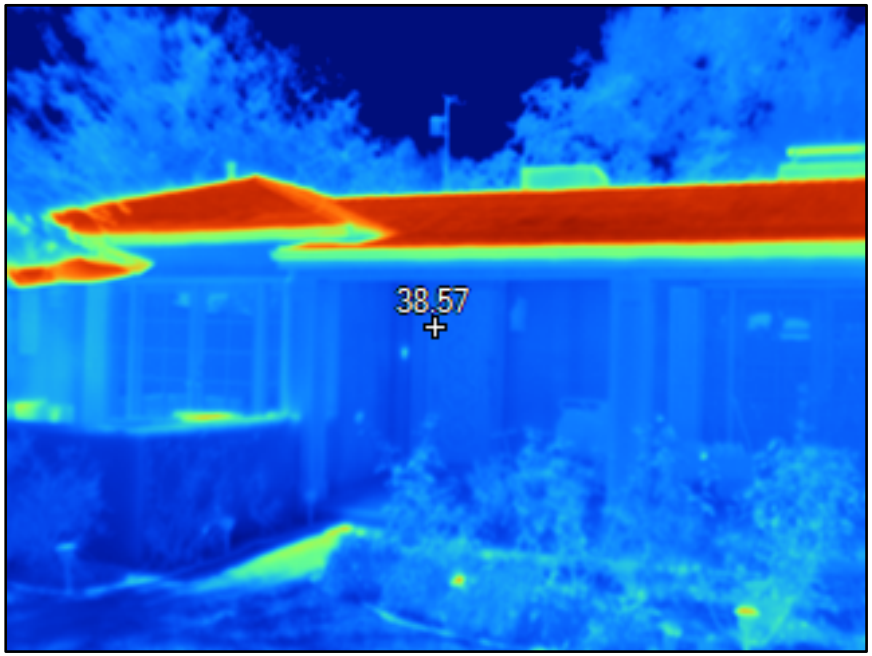
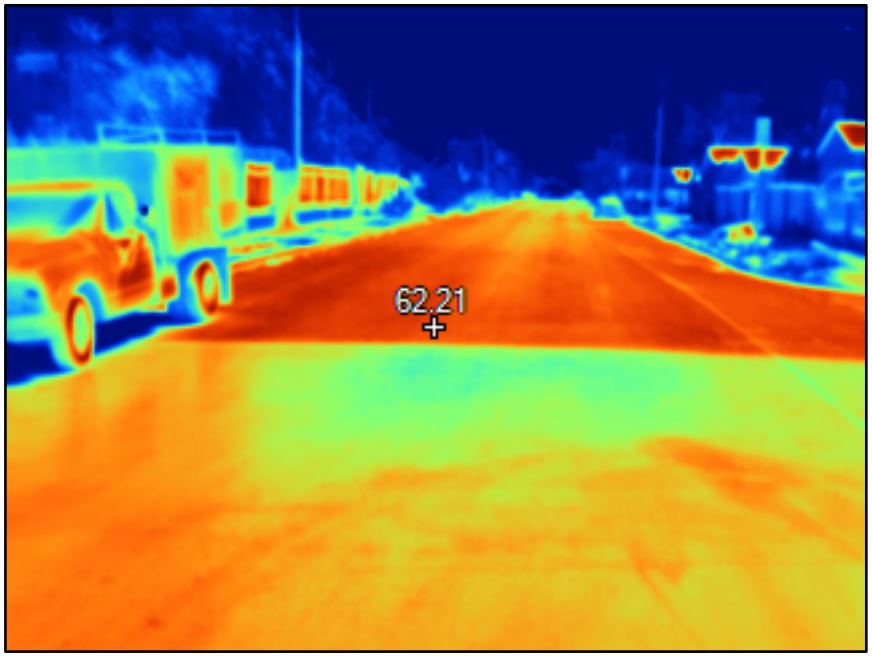
Temporal resolution	Daily	3-5 days	Dedicated campaigns	n/a
Altitude	705 km	400 km	1- 5 km	Ground


FLUKE

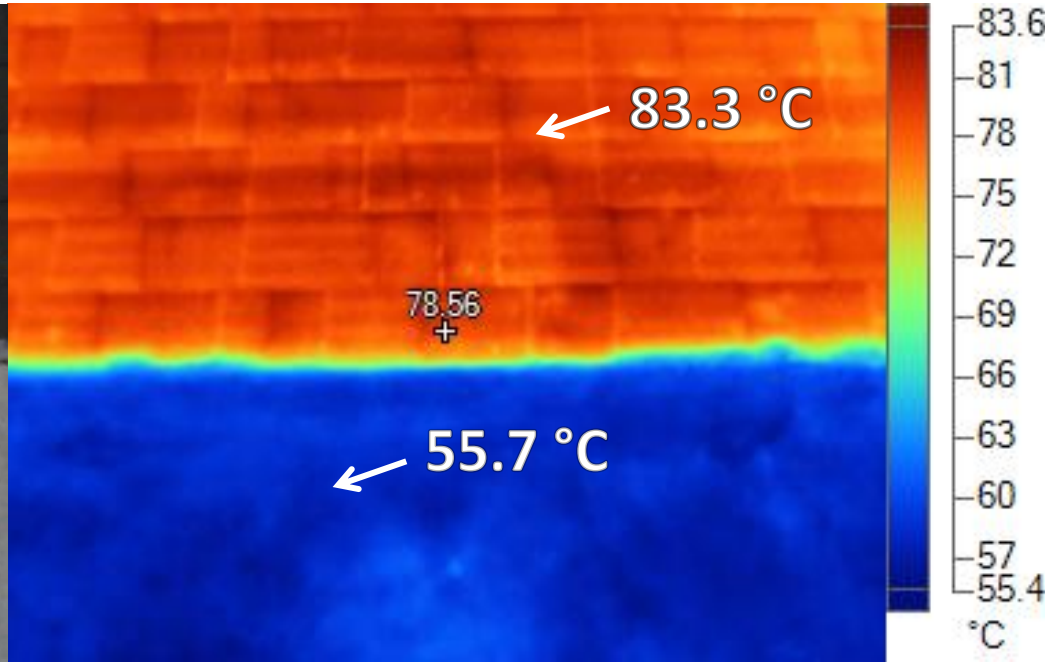

Thermal Image
09/04/2019, 12:41:18


38.57


62.21

Cool Roofs

- White painted vs dark colored shingle, 9/4/2019, 12:45pm, Studio City, Los Angeles
- Surface temperature cooling of up to **27 °C (32%)** due to increased UV reflectivity of white painted surface



Hollywood

West Hollywood

Beverly Hills

Google earth

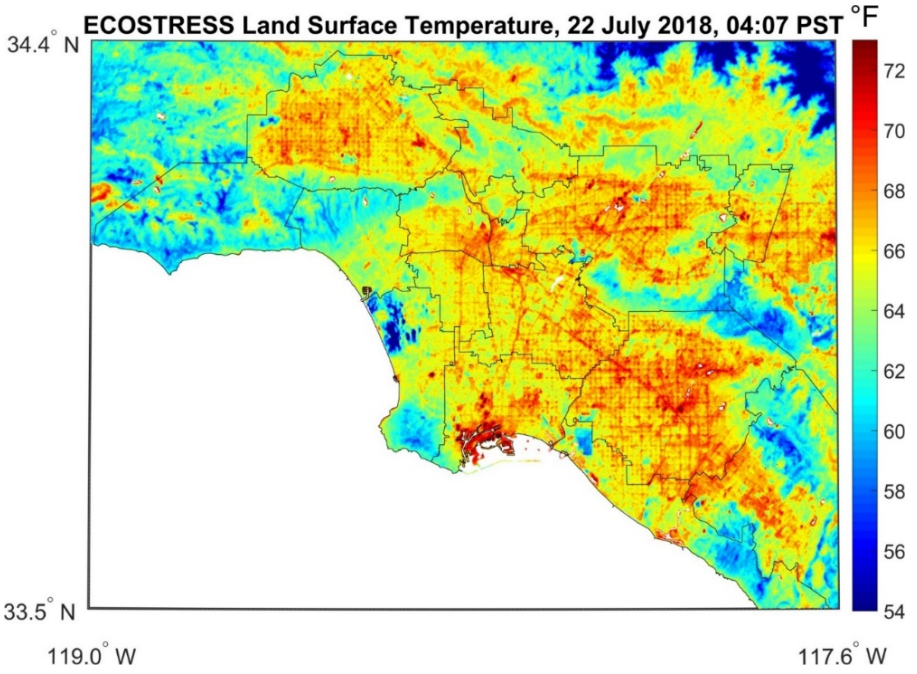
© 2016 Google

N

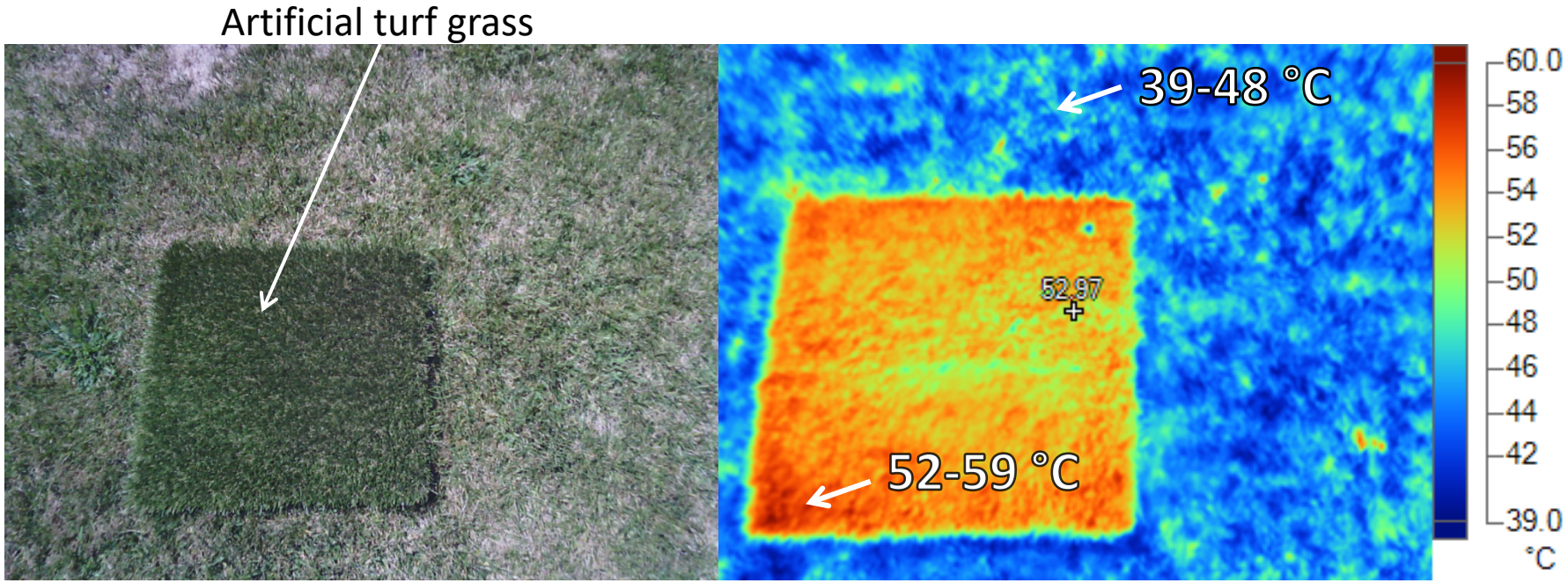
1 mi

In Los Angeles traffic is not ‘cool’, but the roads may soon be....

Jordan Av, Gault St to Hart St (1/2 Street)
Beachy Av, Rangoon St to Reliance St
Etiwanda Av, Napa St to Malden St
70th St, 2nd Av to 3rd Av
Woodbine St, Jasmine Av to Vinton Av
Carmona St, Clemson St to Bowsfield St
Orchard Av, 28th St to 29th St
77th St, Cowan Av to Beland Av
Coronado St, Berkeley Av to Mayberry St
Lord St, 90' S/O Marengo St to Pomeroy Av
President Av, 255th St to 255th St
Bonnie Brae St, 12th St to 12th Pl
Selma Av, Laurel Av to Laurel Canyon Bl
Atoll Av, Barbara Ann St to Gault St
Superior St, Noble to Lemona



Turf grass on average 10 °C warmer than natural grass



Principles of Surface Energy Balance

$$Q^* = H + LE + G$$

Q^* = Net radiation
H = Sensible heat flux
LE = Latent heat flux
G = Storage heat flux

Albedo (reflectivity)

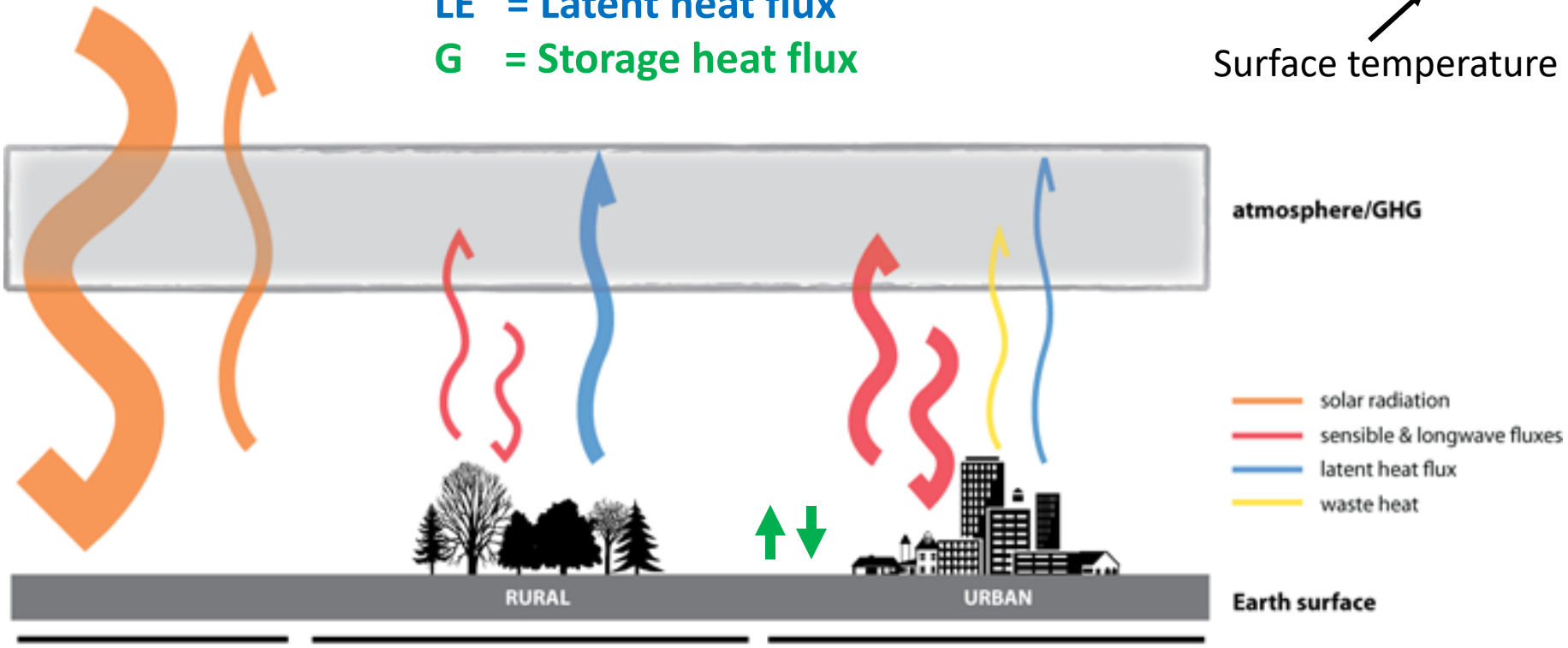
Net radiation $Q^* = K^* + L^*$

Net shortwave $K^* = (1 - \alpha)(K\downarrow)$

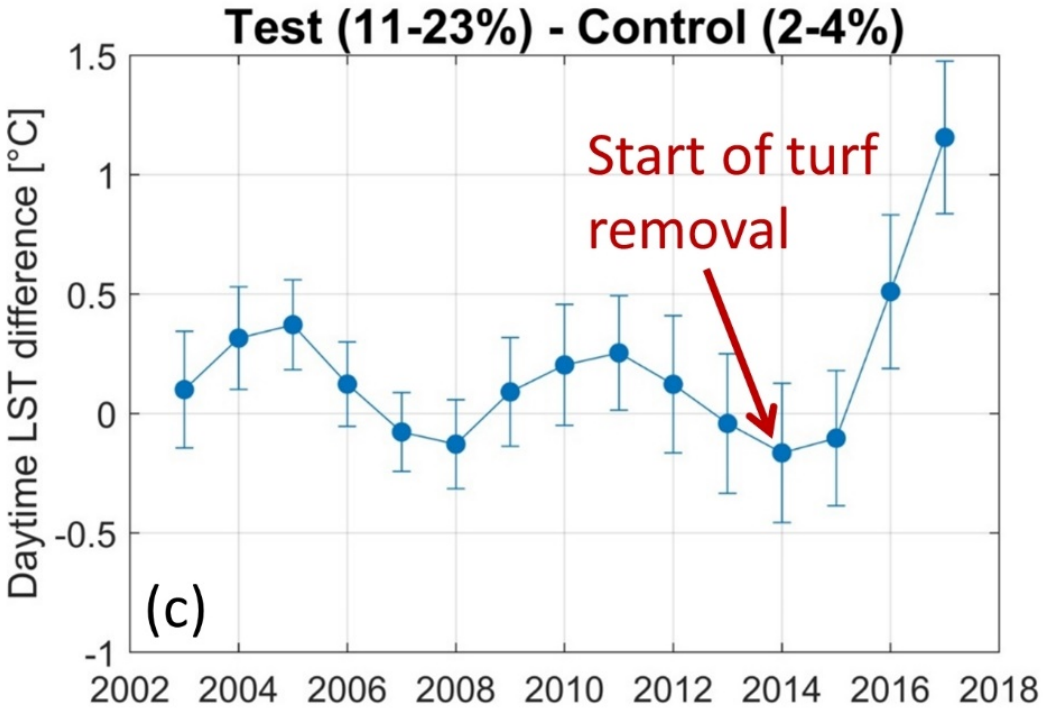
Net longwave $L* = L\downarrow - L\uparrow$

Upward longwave $L\uparrow = \varepsilon[\rho T^4]$

Surface temperature



- Turf replacement (rebate) program in LA (2014) initiated to reduce water consumption during the 2012-2016 drought.
- Rebates were provided to residential and commercial properties in exchange for replacing grass lawns with turf grass and more drought tolerant, efficient landscaping.
- The result was an average warming of daytime air temperatures by 1.9 °C (Vahmani and Ban Weiss 2016) and land surface temperature (LST) by 1.3 °C (Hulley et al. 2019)



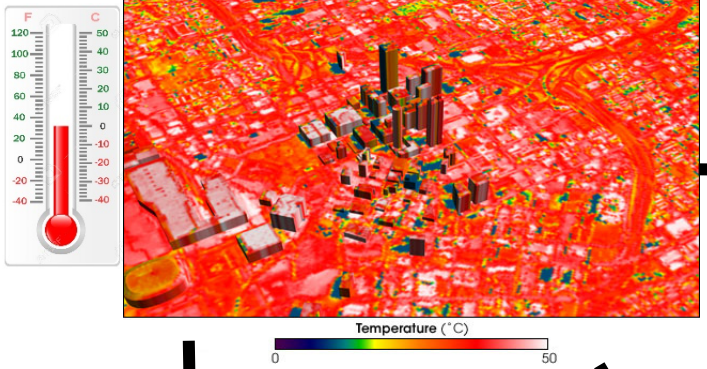
Electric demand
Air conditioning

Energy

Greenhouse gases

Economic cost

Urban Heat Island



Public Health Stress
Water demand

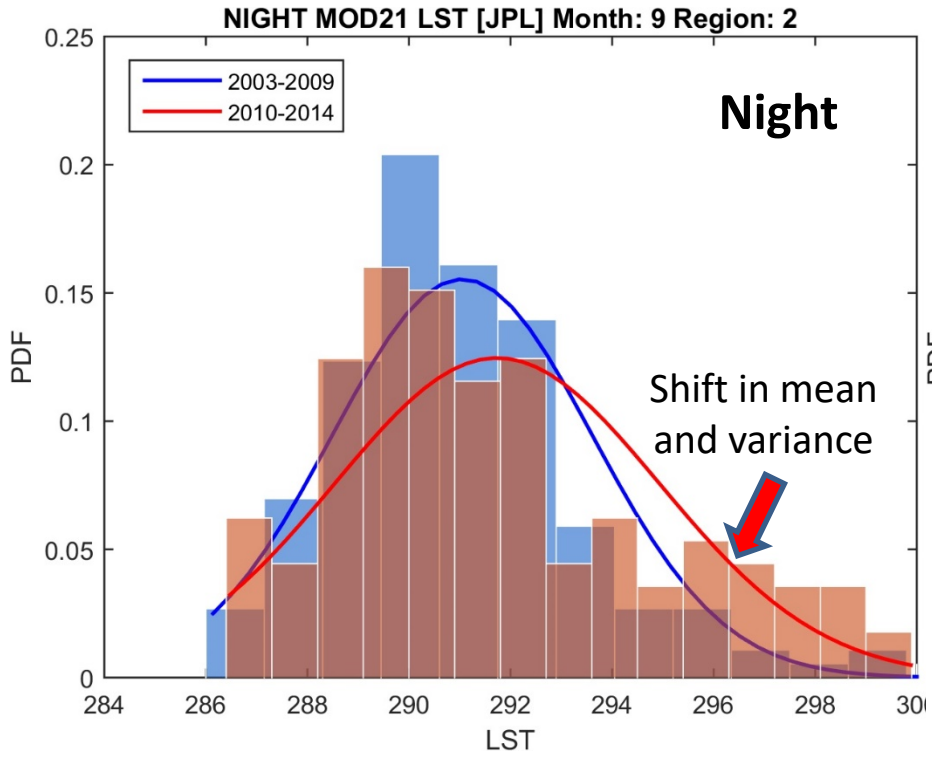
Fires

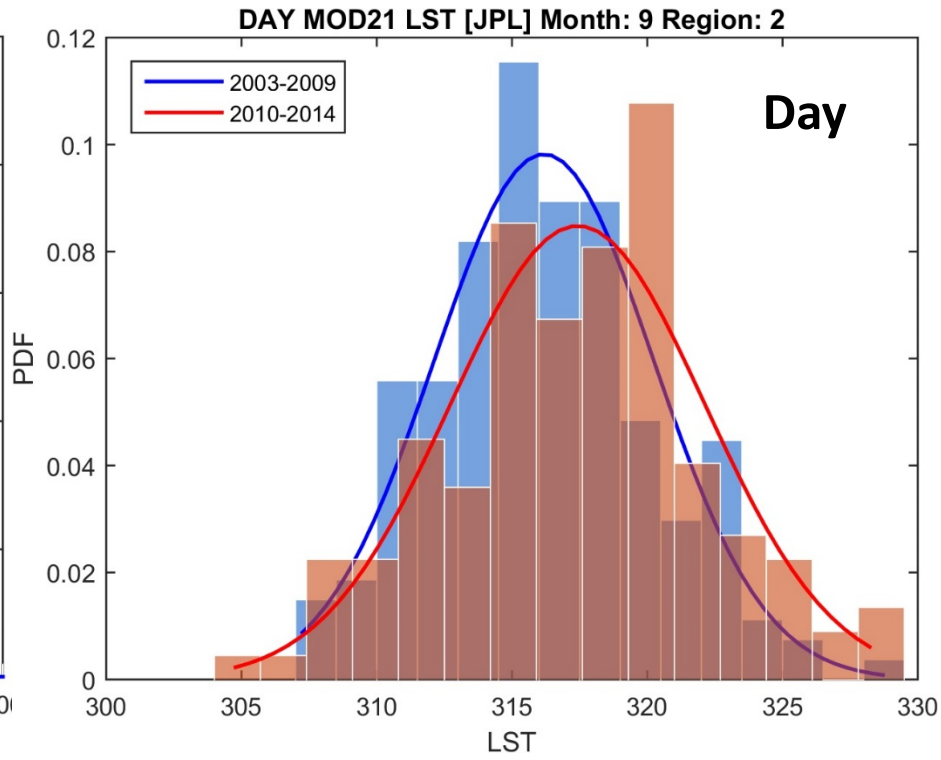
ozone

Air Quality
Smog

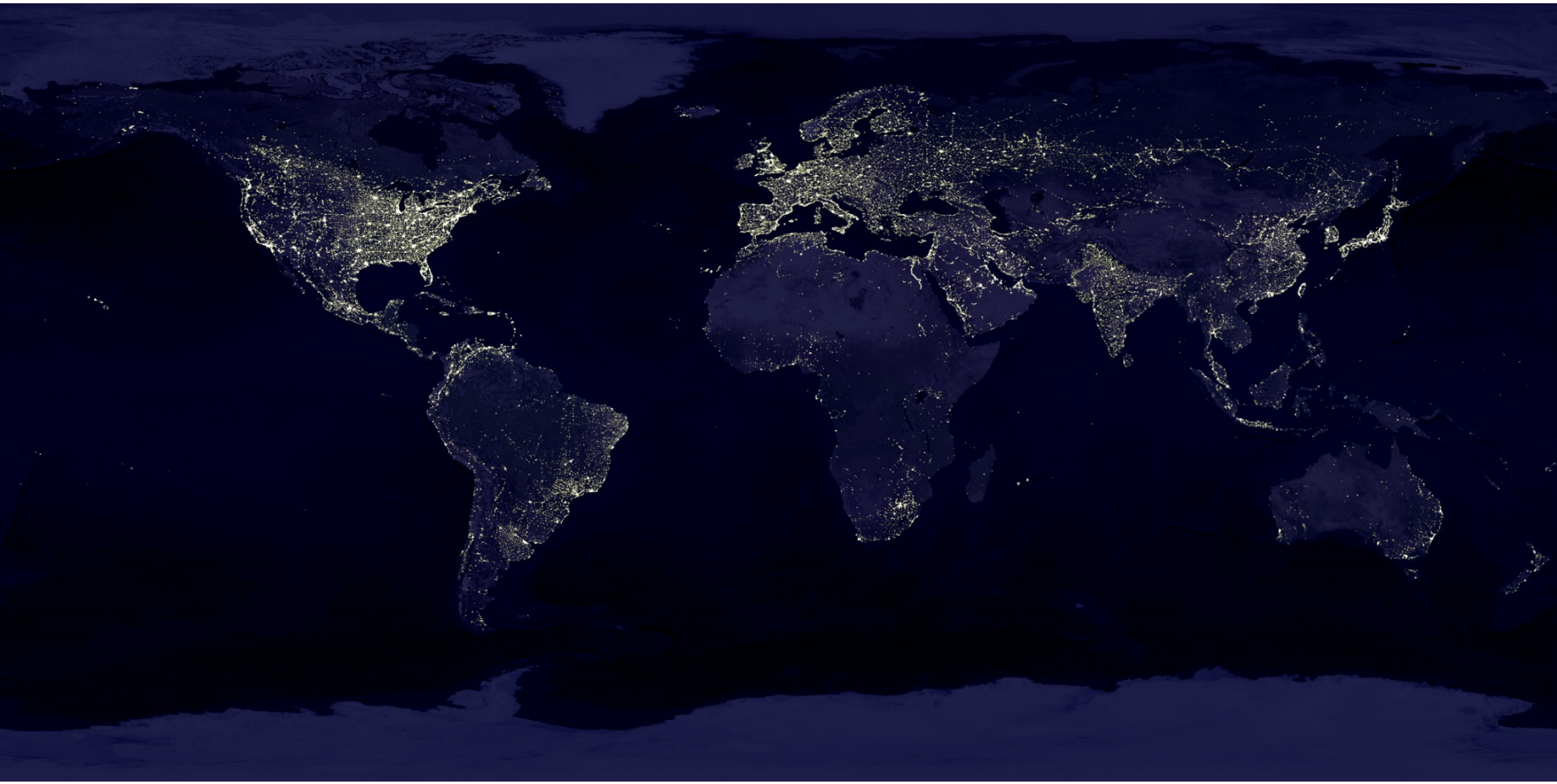
MOD21 day/night LST PDF for [2003-2009] and [2010-2014]

East LA, September





Earth’s city lights from space

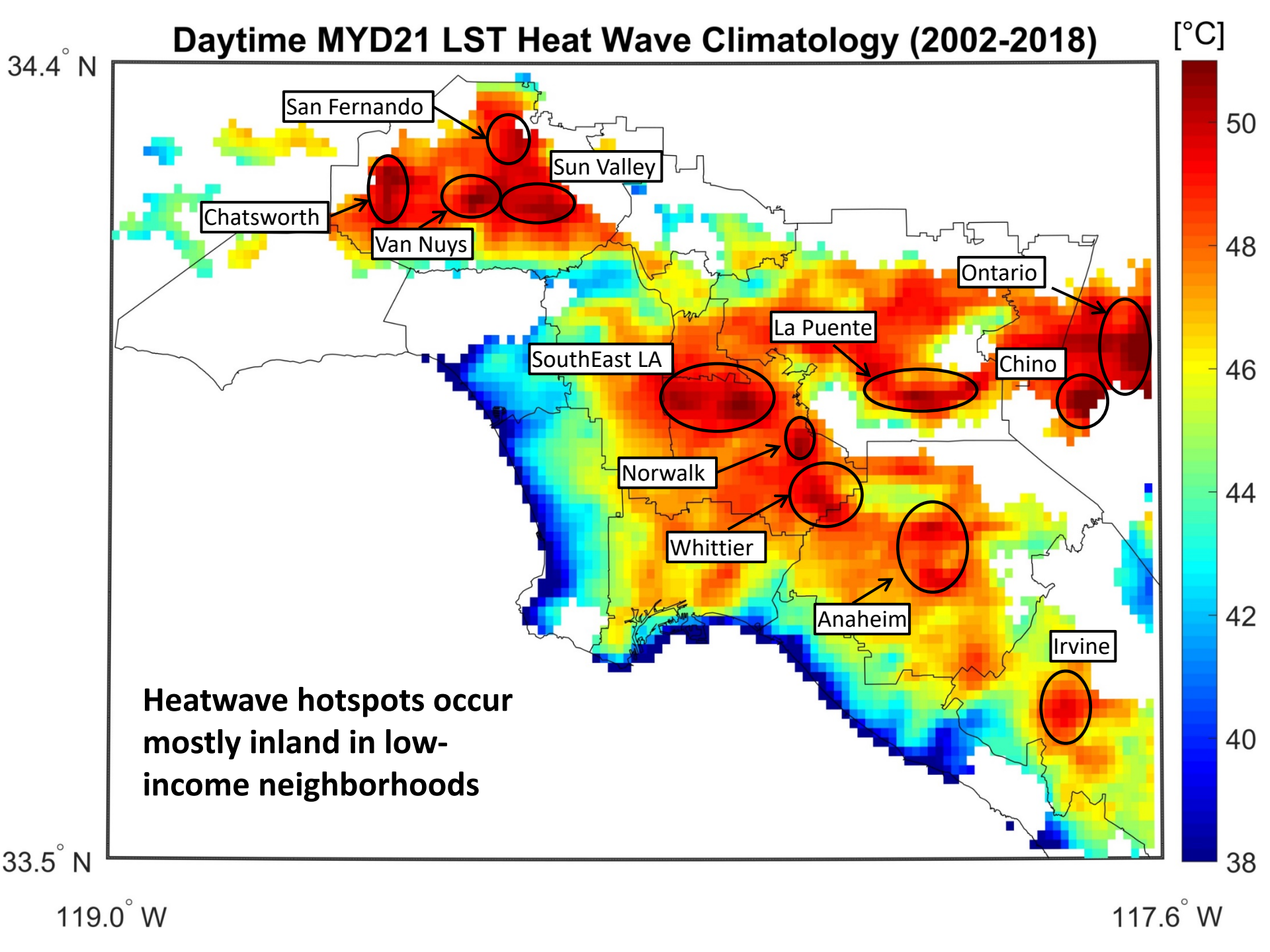


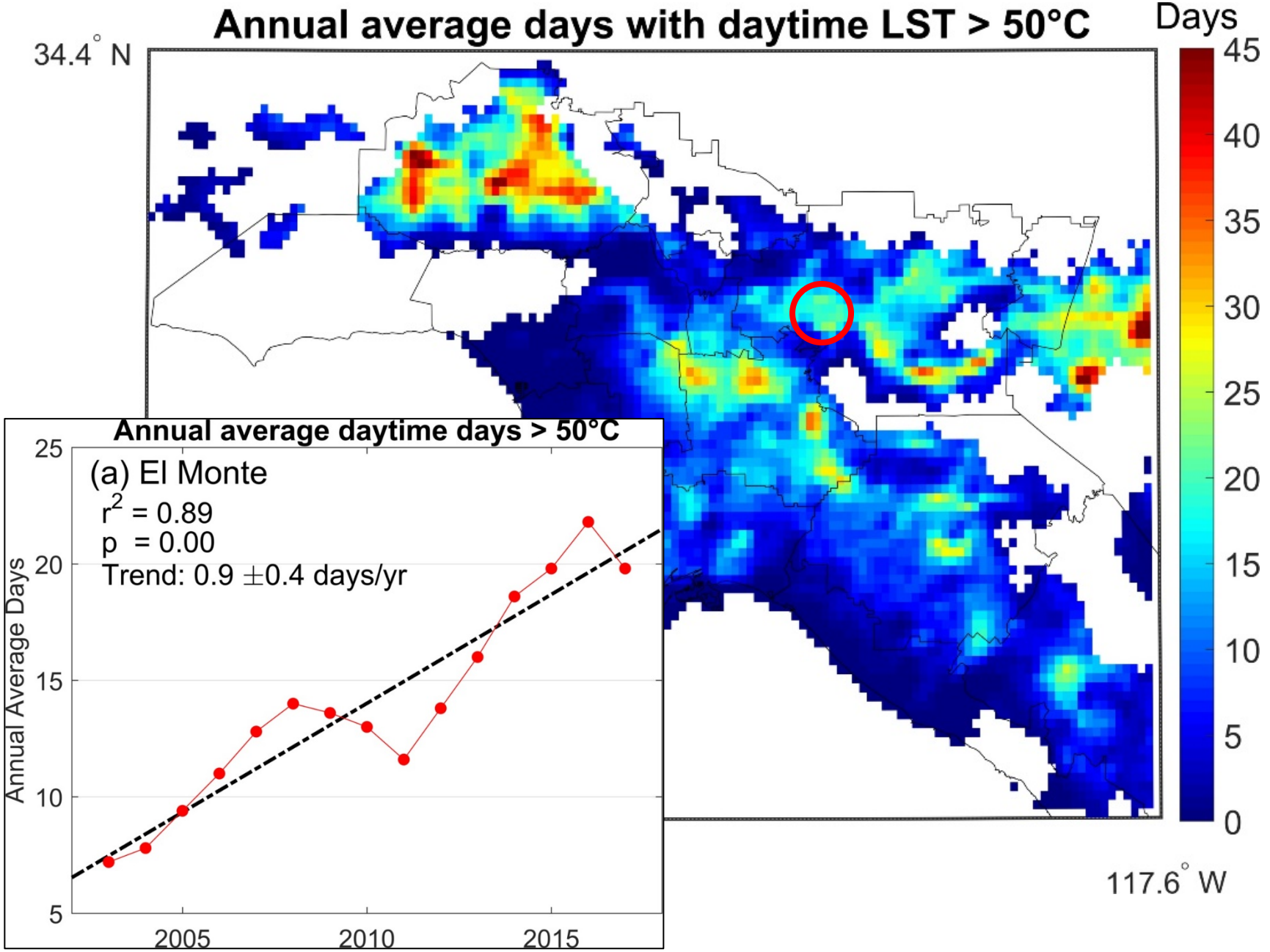
It is estimated that by the year 2050, 68% of the world’s population will live in cities (present day = 55%)

Image courtesy DMSP

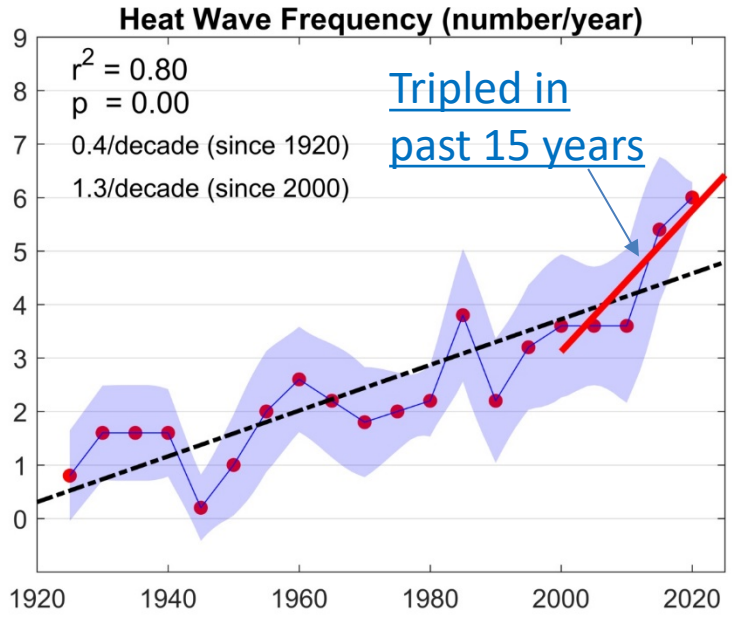
TIR Remote Sensing of Urban Heat

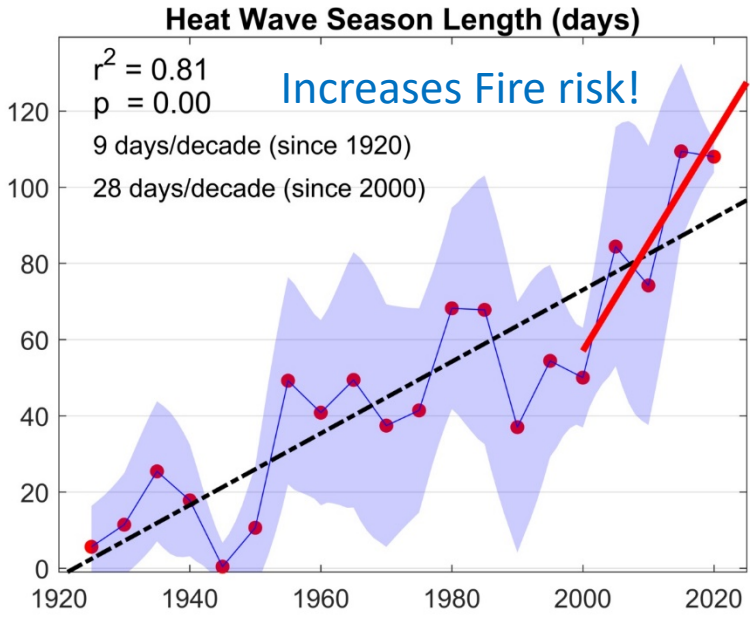
	MODIS (2000/2002)	ECOSTRESS (2018)	HyTES (2013)	Fluke camera
				
Platform	Terra spacecraft	International Space Station	Twin Otter	Hand-held
Spatial resolution	1000 m	70 m	1 - 10 m	0.93 mRad
Temporal resolution	Daily	3-5 days	Dedicated campaigns	n/a
Altitude	705 km	400 km	1- 5 km	Ground

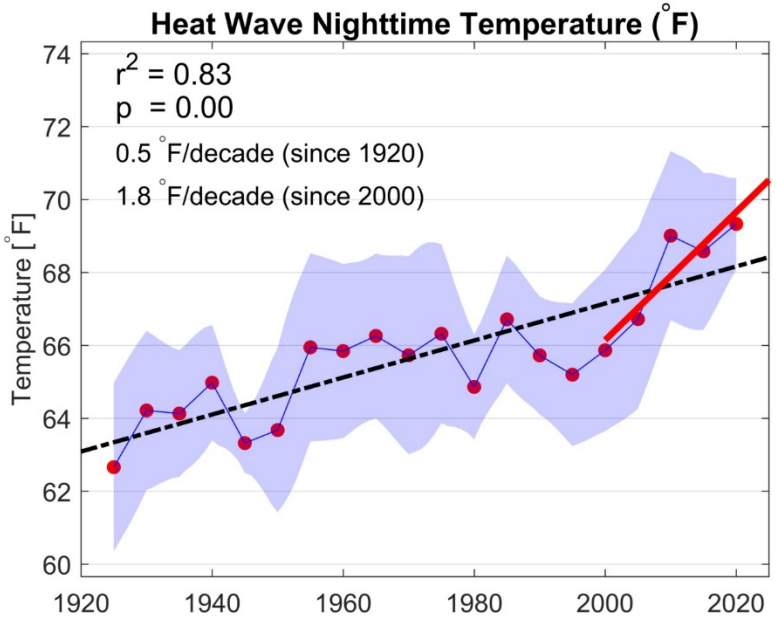

Daytime MYD21 LST Heat Wave Climatology (2002-2018)
[°C]
34.4° N
33.5° N
119.0° W
117.6° W
San Fernando
Sun Valley
Chatsworth
Van Nuys
Ontario
La Puente
SouthEast LA
Chino
Norwalk
Whittier
Anaheim
Irvine
50
48
46
44
42
40
38
Heatwave hotspots occur mostly inland in low-income neighborhoods

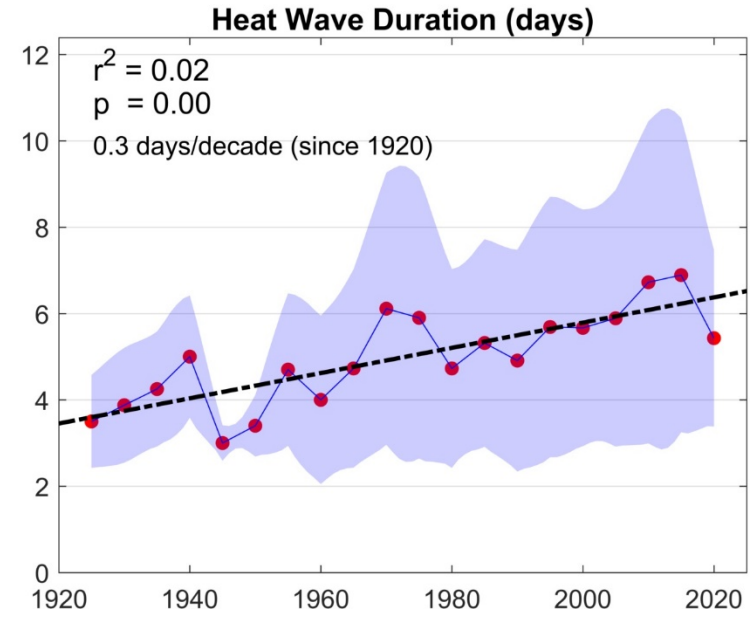

Annual average days with daytime LST > 50°C
Days
45
40
35
30
25
20
15
10
5
0
34.4° N
117.6° W
Annual average daytime days > 50°C
(a) El Monte
r2 = 0.89
p = 0.00
Trend: 0.9 ±0.4 days/yr
Annual Average Days
25
20
15
10
5
2005
2010
2015

SoCal Rising Heat Wave Trends [*Hulley et al, Earth's Future, 2020*]





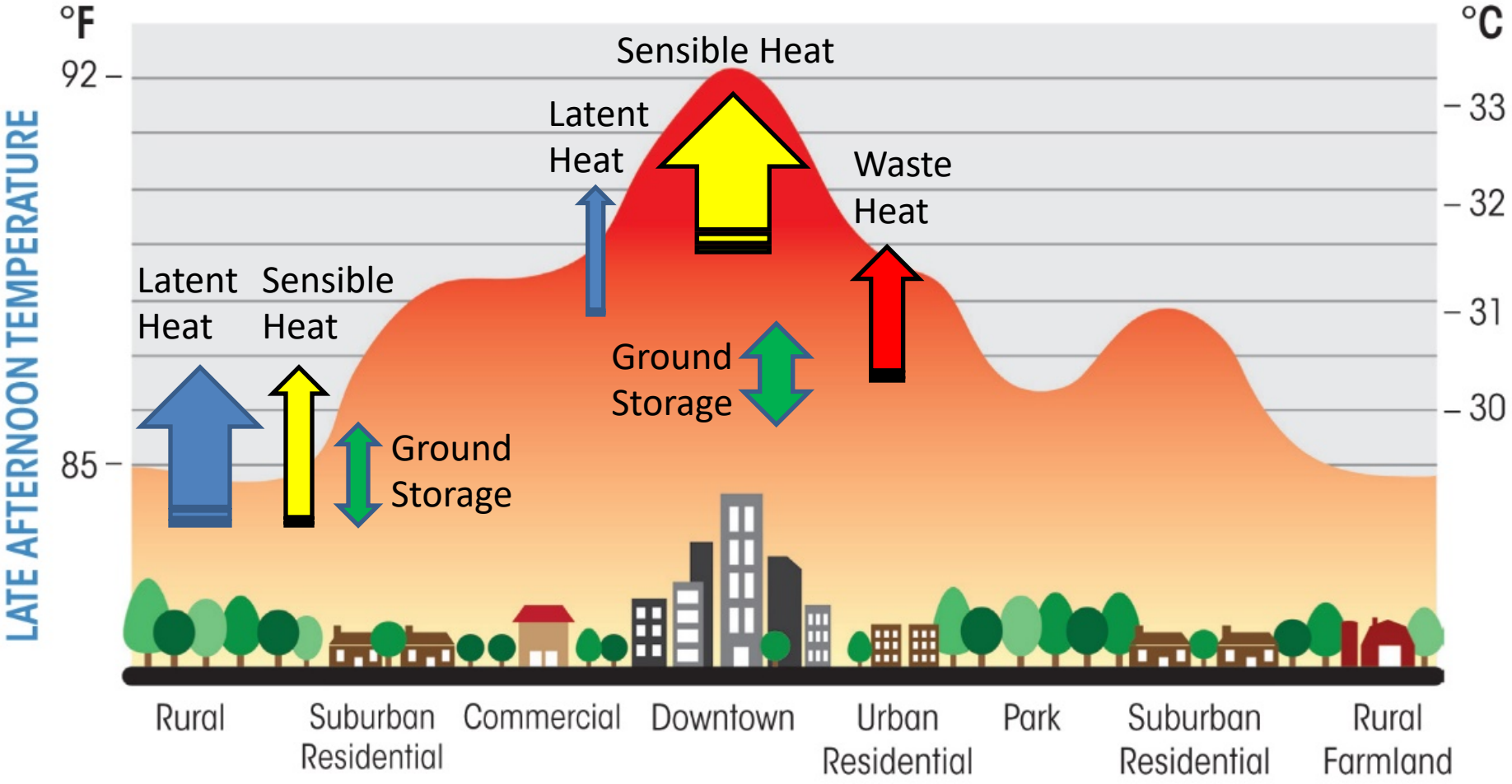




Human health impacts

Urban Heat Island (UHI) Effect

Energy absorbed by man-made materials during day is released slowly at night resulting in heating of air



LA County Sustainability Office heat mitigation and adaptation strategies

Cooling and energy sustainability

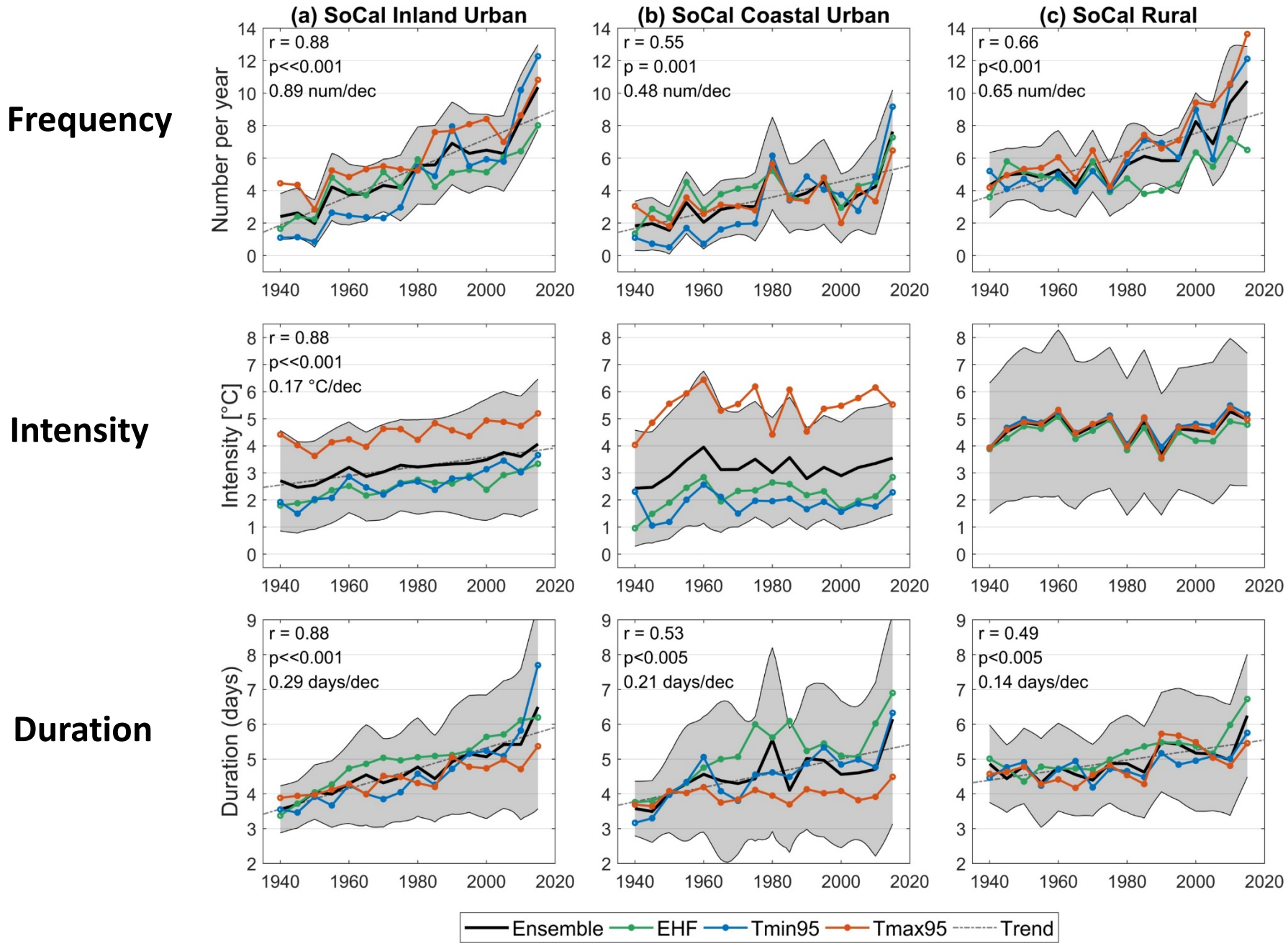
Identify optimal locations for cooling centers

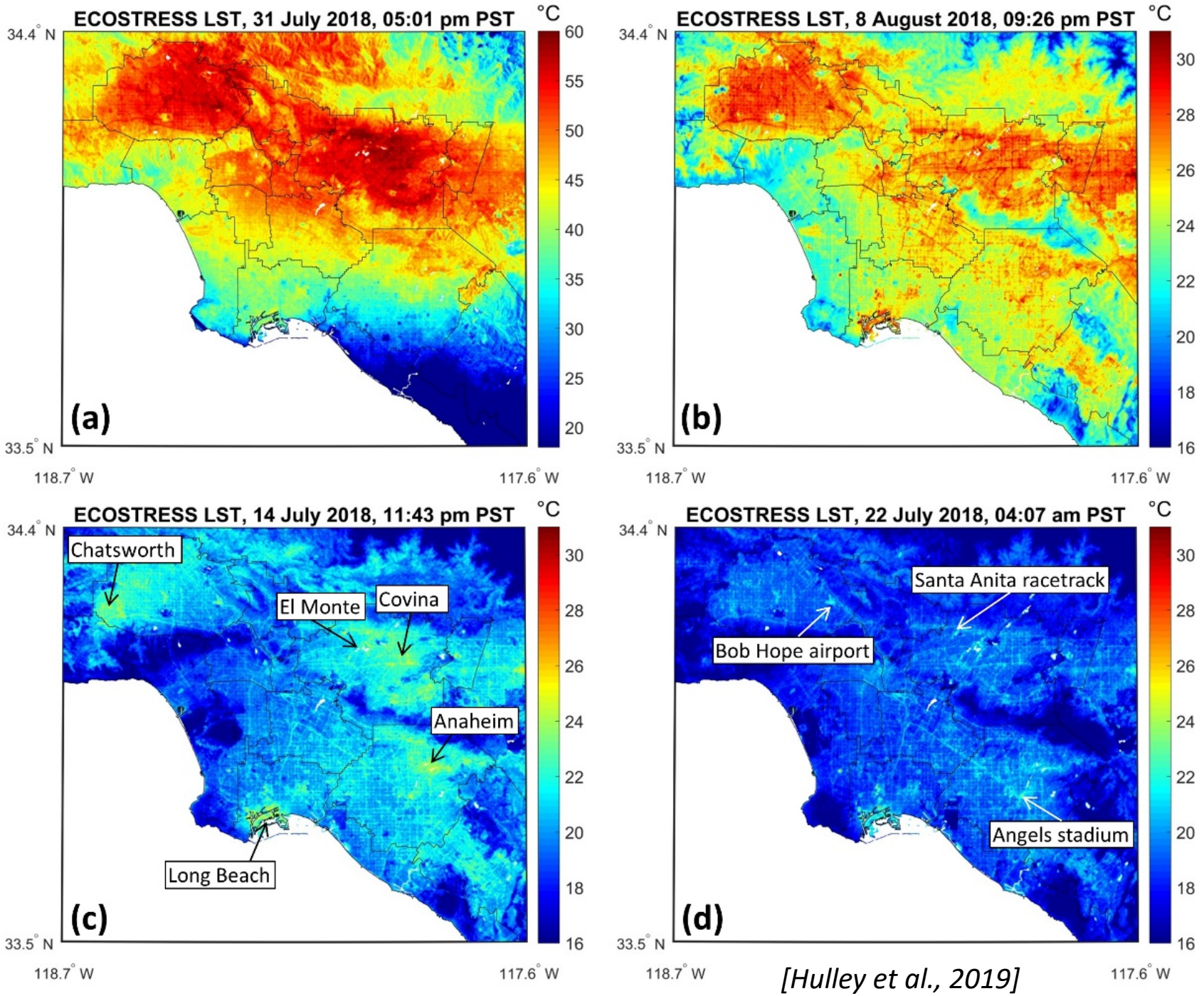
Extreme heat alerts

2018 Health Advisories

Date of Release	Title	
August 01	Air Quality Advisory: Air is unhealthy in Santa Clarita Valley	View
July 30	Air Quality Advisory: Air is unhealthy in Antelope Valley and Santa Clarita Valley	View
July 30	Heat Alert: High temperatures forecast for Pomona area and San Fernando Valley	View
July 29	Air Quality Advisory: Air is unhealthy in parts of LA County	View
July 28	Air Quality Advisory: Air Quality is unhealthy in parts of LA County	View
July 27	Air Quality Advisory: Air is unhealthy in parts of LA County	View
July 26	Air Quality Advisory: Air is unhealthy in parts of LA County	View

SoCal Rising Heat Wave Trends [*Hulley et al, Earth's Future, 2020*]





[Hulley et al., 2019]

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NASA's ECOSTRESS Maps European Heat Wave From Space